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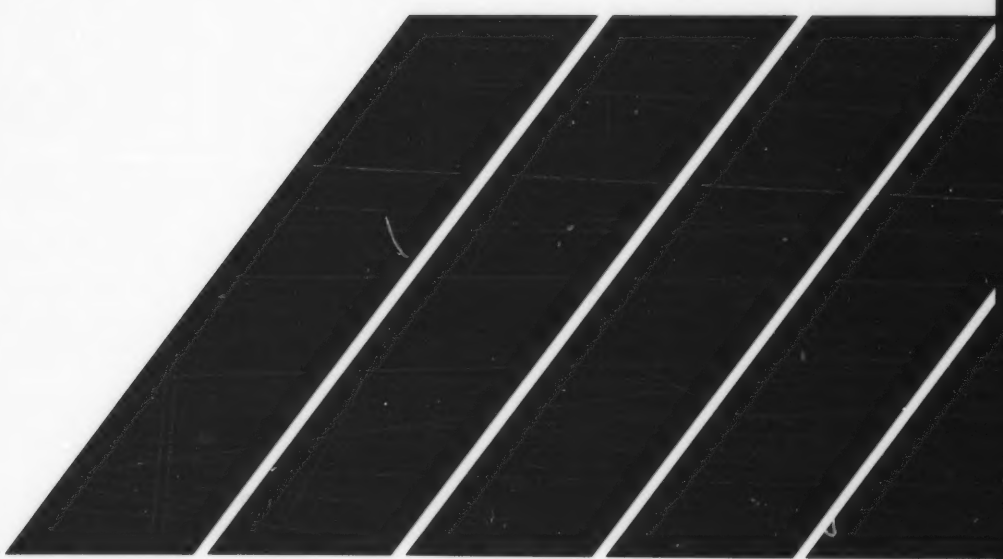

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WATSUN-PV 2.0
USER'S MANUAL AND PROGRAM DOCUMENTATION

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FOREWORD

This manual has been prepared by the WATSUN Simulation Laboratory for use with the group of solar simulation programs entitled WATSUN-PV. It provides the user with a sample session, command descriptions, program architecture, input and output descriptions, and program documentation for system and component models.

A yearly subscription fee will provide the user with all required additions, corrections and revisions for any changes made to the program. It was also provide the user with new versions.

Every effort has been made to ensure the accuracy of the information contained in this manual. However, if errors or omissions are detected, please notify the WATSUN Simulation Laboratory so that problems may be corrected.

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EXECUTIVE SUMMARY

Computer tools for the simulation of photovoltaic (PV) systems operating under extreme conditions of low insolation, low temperature and in remote areas are required by users and designers of systems for northern Canadian sites.

In collaboration with the Watsun Group of the University of Waterloo and TdS Dixon Inc., ORTECH International has extended and optimised the capabilities of WATSUN-PV. This program can simulate and evaluate the performance of stand-alone low-power PV systems with battery storage.

The effects of different control strategies and the additions of a diesel generator set and battery life-time on system performance were studied. Models were then developed for integration into what became version 3.0 of WATSUN-PV.

Remote northern Canadian sites are prime candidates for the widespread application of PV/diesel hybrid systems. However, the questions of capital cost and reliability have not been totally resolved. The work in this project contributes to a better understanding of the interaction between the different components of hybrid systems. It also provides a tool to assess the overall performance of the system.

New models were developed for the PV array and the battery to support the integration of five different control strategies and their comparison. They also make WATSUN-PV easier to use.

The new array model predicts hourly current and voltage conditions (I-V model) as a function of temperature and solar radiation. It also accepts model parameters available from manufacturers. Studies of the system control strategies included the following:

- maximum array power-tracking with limiting battery voltage;
- maximum array power-tracking with battery trickle-charging;
- clamped array voltage with limiting battery voltage;
- clamped array voltage with battery trickle-charging;
- and direct coupling between the array and the battery.

The simplest way of comparing the various control strategies would be to simulate them on five systems with identical component sizing, load requirements and meteorological data, and then compare their performance. However, in practice, choosing one strategy over another is guided by economics.

Therefore, the comparison was done by resizing each of the systems so they performed to the same level in terms of reliability and meeting the load. Any comparisons between systems can then be based on the relative component sizing and the corresponding cost savings or penalties.

Although this repetitive process takes longer, the results can be used directly in an economic analysis.

The comparison of five strategies was done for a remote site located at Inuvik, N.W.T. The maximum power point tracked system required less storage. The trickle charger failed to make efficient use of the available energy from the array. Both the clamped and direct-coupled systems performed more or less the same. The lack of charge regulation did not appear to affect the system's ability to meet the load. Although unavailable in the current version of WATSUN-PV, a tabulation of gassing current could show that the direct-coupled system allows heavy battery gassing. Therefore, this approach is not favoured from an operational point of view.

A similar set of results were obtained by reducing the array size and adding batteries. The margin of the system's reliability, i.e. the minimum remaining obtainable charge in the battery, depended strongly on the array size.

The main conclusion from this part of the work is that no major differences in system performance were observed due to the control strategy adopted. The choice of any particular strategy remains a decision of economics, after the type of battery and array that will be employed are determined.

The enhanced battery model is temperature-sensitive and based on I-V characteristics. The model describes current-voltage behaviour rather than electrochemical behaviour. In its present format, the model accepts battery parameters in the form of voltage versus time and gassing versus voltage data. A complete default data set based on a typical lead-acid battery is provided to allow the user to perform simulations without any battery data other than capacity. The user can modify the input curves point-by-point using specific battery data.

Battery self-discharging and self-heating and other minor effects were not modelled since their effects may not be significant in the applications discussed here.

Long-term battery aging effects in a PV system are important because the knowledge of the anticipated battery life under a set of operating conditions allows its replacement before failure can occur. The incorporation of a battery aging model into a PV system simulation provides the designer with the tools to determine the effect of component sizing on battery discharge

characteristics and, consequently, battery life.

The aging model developed in this project tracks the aging, but does not modify the performance characteristics of the battery over its life. This passive approach is justified because the greatest effect of age is on capacity. At the end of an annual simulation, the user is given a report on the reduction of life suffered by the battery, the life expectancy under the same conditions, and the volume of electrolyte lost to gassing.

In a PV/diesel hybrid system in a typical northern Canadian site, the diesel generator operates mainly during the winter months to recharge the battery and power the load. The batteries supply the load for only a few days. During the summer, the PV array and the batteries meet most of the energy requirements of the system. The generator operates for only a few hours a month, for maintenance procedures.

In the model implemented here, the diesel generator was characterized by its capacity and the criterion for activating it, based on the status of the rest of the hybrid system. The amount of fuel consumed depends on the altitude, temperature and type. Fuel efficiency curves were fitted to the cubic spline routines of WATSUN-PV, and then derated for altitude and temperature.

The diesel generator always starts and stops on the hour. When it is called during the hour, the simulation is repeated. This simplification provided a form of hysteresis needed to prevent the generator from cycling on and off frequently.

The PV/diesel and battery aging models have been integrated into version 3.0 of WATSUN-PV. Systems simulations will be done by the Watsun Group once the program has been fully debugged. It is intended that two remote stand-alone systems with the same array, but different annual energy distributions, will be simulated. The results will be available to users and designers to conduct long-term economic analyses. This will allow the examination of the sensitivity of overall system costs to the correct battery and array sizings.

Several tasks remain to make WATSUN-PV a useful program for the assessment of designs and feasibility of PV/diesel hybrid systems for remote northern Canadian sites.

In order for WATSUN-PV to be adopted by a broad spectrum of users, the program should be as user-friendly as possible. The integration of user interfaces, as well as the programming and debugging of user codes, are more easily executed in Pascal than in Fortran, which is currently used by WATSUN-PV. Pascal's more modular nature facilitates the integration of codes from multiple contributors.

The battery continues to be the most difficult component to model accurately because of its time dependence. It is recommended that high accuracy tests be performed with very well controlled current or voltage and temperature parameters to provide cycle repeatability. The results of these tests can be used to refine the mathematical model structure and improve battery default parameters. Long-term battery performance data are also required to quantify the aging model implemented here.

In addition, another version of the PV/diesel model should follow once the current model has been exercised by various interested parties, and improvements and simplifications have been suggested.

The seemingly very different tasks carried out in the present work have significantly enhanced WATSUN-PV and made it an effective simulation tool for low-power PV systems for the Canadian north. Further improvements to the program should be realized by the combination of work remaining and the experienced gathered by third parties in the actual application of the software to real systems.

RÉSUMÉ

Les utilisateurs et concepteurs de systèmes photovoltaiques (PV) à des sites du Nord canadien ont besoin d'outils informatiques de simulation de ces systèmes dans les conditions extrêmes de faible insolement, de basse température et d'éloignement,

En collaboration avec le Groupe Watsun de l'University of Waterloo et de TdS Dixon Inc., ORTECH International a étendu et optimisé les ressources du logiciel WATSUN-PV. Ce programme peut simuler et évaluer les performances des systèmes PV basse puissance autonomes à batterie d'accumulateurs.

On a étudié les effets des différentes techniques de commande, de l'addition d'une génératrice Diesel et de la durée de vie des batteries sur les performances de système, et des modèles ont ainsi été élaborés en vue de leur intégration à ce qui est devenu la version 3.0 de WATSUN-PV.

Les sites éloignés du Nord canadien se prêtent bien à l'application générale des systèmes hybrides PV-Diesel. Les questions d'investissement initial et de fiabilité n'ont toutefois pas encore été totalement résolues. Les travaux décrits dans le rapport contribuent à une meilleure compréhension de l'interaction entre les différents éléments des systèmes hybrides, et ils fournissent un outil d'évaluation des performances des systèmes dans leur ensemble.

De nouveaux modèles de réseau PV et de batterie ont été élaborés dans le but d'appuyer l'application et la comparaison de cinq différentes techniques de commande et de simplifier l'utilisation de WATSUN-PV.

Le nouveau modèle de réseau prédit les conditions horaires de courant et de tension (modèle I-V) en fonction de la température et du rayonnement solaire. Il admet aussi les paramètres de module qui sont disponibles des fabricants. Les techniques de commande de système qui ont été étudiées étaient les suivantes :

- poursuite de la puissance maximale du réseau avec tension de limitation de la batterie
- poursuite de la puissance maximale du réseau avec charge d'entretien de la batterie
- calage de la tension de réseau avec tension de limitation de la batterie
- calage de la tension du réseau avec charge d'entretien de la

batterie

■ couplage direct entre le réseau et la batterie

La façon la plus simple de comparer les diverses techniques de commande aurait consisté à les simuler sur cinq systèmes dans des conditions identiques de taille des éléments, de courant de charge et de données météorologiques, puis à comparer leurs performances. Dans la pratique, le choix d'une technique plutôt que d'une autre repose toutefois sur des critères économiques. On a donc effectué la comparaison en changeant la taille de chacun des systèmes de manière à obtenir les mêmes performances du point de vue de la fiabilité et de la charge. Toute comparaison entre les systèmes se fondera sur la taille relative des éléments et sur les économies ou les coûts correspondants.

Le processus itératif est plus laborieux, mais les résultats peuvent être utilisés directement dans une analyse économique.

La comparaison des cinq techniqes a été effectuée pour un site éloigné (Inuvik, T.-N.-O.). Le système de poursuite du point de puissance maximale nécessitait moins d'accumulateurs. Le chargeur d'entretien ne faisant pas une utilisation efficiente de l'énergie fournie par le réseau. Les systèmes à calage et à couplage direct se comportaient essentiellement de la même façon. L'absence de régulation de charge n'a pas semblé influer sur l'aptitude du système à supporter la charge. Bien que non disponsible dans la version actuelle de WATSUN-PV, un tableau des courants de dégagement gazeux pourrait montrer que le système à couplage direct permet un dégagement plus intense, ce qui n'est pas souhaitable du point de vue de l'exploitation.

La réduction de la taille du réseau et l'augmentation du nombre de batteries ont donné des résultats semblables. La marge de fiabilité du système, soit la charge résiduelle minimale de la batterie, était fortement liée à la taille du réseau.

La principale conclusion que l'on puisse tirer de cette partie des travaux est qu'aucune différence majeure de performances des systèmes n'était liée à la technique de commande adoptée. Le choix d'une technique particulière demeure une décision économique, une fois que l'on a déterminé le type de batterie et de réseau à employer.

Le modèle de batterie amélioré est lié à la température et repose sur les caractéristiques I-V. Il décrit les caractéristiques courant-tension, plutôt que les caractéristiques électrochimiques. Sous sa forme actuelle, it admet les paramètres des batteries sous forme de tension en fonction du temps et de dégagement gazeux en fonction de la tension. Une fiche complète de données implicites est donnée pour une batterie au plomb typique, afin de permettre à l'utilisateur d'effectuer

des simulations sans données autres que la capacité. L'utilisateur peut modifier les courbes d'entrée point par point à l'aide de données propres aux batteries.

La décharge spontanée et l'auto-chauffage de la batterie, ainsi que d'autres effets mineurs, n'ont pas été incorporés au modèle, étant donné que leur rôle peut être négligeable dans les applications en cause.

Les effets du vieillissement à long terme des batteries dans un système PV ont leur importance, car ce n'est qu'en connaissant la durée de vie prévue d'une batterie dans un ensemble de conditions opérationnelles qu'il est possible d'effectuer un remplacement avant que ne se produisent des défaillances. L'intégration d'un modèle de vieillissement de batterie à un programme de simulation de système PV donne au concepteur les outils nécessaires pour déterminer l'incidence de la taille des éléments sur les caractéristiques de décharge d'une batterie, et donc sur la durée de vie de celle-ci.

Le modèle de vieillissement établi pour ce projet suit le vieillissement, mais ne modifie pas les caractéristiques de la batterie selon la période de la durée de vie. Cette passivité se justifie du fait que le plus grand effet du vieillissement se fait sentir sur la capacité. A la fin d'une simulation annuelle, l'utilisateur obtient un rapport de la réduction de durée de vie de la batterie, de la durée de vie prévue dans les mêmes conditions et du volume d'électrolyte perdu en dégagement gazeux.

Dans un système hybride PV-Diesel utilisé à un site typique du Nord canadien, la génératrice Diesel fonctionne principalement durant les mois d'hiver pour recharger la batterie et alimenter la charge. Suivent ensuite quelques jours pendant lesquels les batteries alimentent la charge. Durant l'été, le réseau PV et les batteries satisfont à la majeure partie des besoins du système. La génératrice ne fonctionne que quelques heures par mois à des fins de maintenance.

Dans le modèle dont il est question ici, la génératrice Diesel se caractérise par sa capacité et son déclenchement est lié à l'état du reste du système hybride. Le carburant consommé dépend de l'altitude, de la température et du type utilisé. Les courbes d'efficience d'utilisation du carburant ont été adaptées aux routines à fonction pistolet cubique de WATSUN-PV, puis soumises à un abaissement des valeurs tenant compte de l'altitude et de la température.

C'est toujours à l'heure juste que la génératrice Diesel se met en marche et s'arrête. La simulation se répète lorsqu'un appel se produit entre temps. Cette simplification fournit la forme d'hystérésis nécessaire pour empêcher la génératrice de suivre un cycle de fréquentes mises sous tension et hors tension.

Les modèles PV-génératrice Diesel et de vieillissement de batterie ont été intégrés à la version 3.0 de WATSUN-PV. Le groupe Watsun effectuera les simulations de système une fois que le programme aura été complètement débogué. On prévoit simuler deux systèmes autonomes éloignés utilisant le même réseau, mais fonctionnant selon différentes distributions annuelles d'énergie. Les résultats seront mis à la disposition des utilisateurs et des concepteurs en vue d'analyses économiques à long terme. Il sera ainsi possible d'examiner dans quelle mesure les coûts totaux de système dépendent du choix de la batterie appropriée et de la taille du réseau.

Plusieurs tâches demeurent encore pour faire de WATSUN-PV un programme utile d'évaluation de la conception et de la faisabilité des systèmes hybrides PV destinés aux sites éloignés dans le Nord canadien.

Pour être adopté par un large éventail d'utilisateurs, WATSUN-PV doit être aussi convivial que possible. L'implantation des interfaces utilisateurs ainsi que la programmation et le débogage des codes d'utilisateur s'effectuent plus facilement en Pascal qu'en Fortran, soit le langage actuellement utilisé par WATSUN-PV. Le nature plus modulaire du Pascal facilite l'intégration des codes d'origines multiples.

En raison de ses liens complexes avec le temps, la batterie est toujours l'élément le plus difficile à modéliser adéquatement. Il est recommandé de soumettre les accumulateurs à des essais de haute précision en utilisant des paramètres très rigoureux de courant ou de tension ainsi que de température, de manière à assurer la répétabilité du cycle. Les résultats de ces essais peuvant servir à raffiner la structure du modèle mathématique et à améliorer les paramètres implicites des batteries. Des données sur les performances à long terme des batteries sont également nécessaires à la quantification du modèle de vieillissement dont il est question ici.

Enfin, une autre version du modèle PV-Diesel devrait être établie une fois que le modèle actuel aura été mis à l'épreuve par les différents intéressés et que les améliorations et simplifications auront été proposées.

Les tâches apparemment fort différentes effectuées dans le cadre des présents travaux ont contribué de façon importante à l'amélioration de WATSUN-PV ainsi qu'à son utilisation comme outil de simulation efficace pour les systèmes PV basse puissance dans le Nord canadien. Le programme devrait encore être amélioré par l'ensemble des travaux qui restent à exécuter ainsi que par l'acquisiton d'expérience par des tierces parties dans l'application effective logiciel à des systèmes réels.

1 Introduction

This chapter provides the user with basic information needed to access and run the WATSUN-PV program. It is intended for those who are not familiar with WATSUN-PV, but will also aid the infrequent user. It explains how to access the WATSUN-PV program for mainframe and microcomputer installations. By stepping through the sample session in section 1.3 WATSUN-PV Tutorial, the user will be able to simulate a solar system within a half hour.

1.1 Running WATSUN-PV on the WATSUN Simulation Laboratory Computer

To logon to the WATSUN Simulation Laboratory microVAX computer, the user needs an ASCII terminal, a modem, and a computer account with the WATSUN Simulation Laboratory. When this account is set up, the user receives a Network User ID or NUI and a password.

The NUI is the user's identification code and is usually UOFW and three digits. The password is supplied with the NUI and they must be used together as given.

1.1.1 Logon Procedure

Once the user has the necessary hardware and a valid WATSUN Simulation Laboratory computer account, access may be obtained through the DATAPAC Communications Network. DATAPAC is accessible through a local telephone number (listed in the telephone book unser DATAPAC) in most Canadian cities for baud rate of 110, 300, and 1200 bps. The logon procedure is as follows:

1. Dial the DATAPAC number and connect the modem
2. For 300 baud - Type one period (.) and press RETURN

   For 1200 baud - Type two periods (..) and press RETURN

   The response should be similar to the following:

DATAPAC: 2040 0273

---

3. Supply the Network User ID by typing NUI plus any one of the following three NUI's: UOFW110, UOFW111, or UOFW112

NUI UOFW110

You will be prompted for the password. The password must go with the appropriate NUI (upon purchasing or connecting to WATSUN, the password will be given to you).

NUI: UOFW110 Password
UOFW111 Password
UOFW112 Password

If this prompt is not received, refer to section 1.1.2 DATAPAC Access Refused.

4. Press <RETURN>. DATAPAC will respond with a message informing you that the NUI is being charged.
5. Type 33600195 and <RETURN>. DATAPAC will respond with a connection message and a NUI charging signal. You will receive a Private Intelligent Networker (PIN) prompt.

PIN: Call connected
Channel reconnected

---

6. <RETURN>. A Sytek prompt "@" will appear. Type Call 103D or 103E if 103D is busy. The response will be:

WATSUN Simulation Laboratory
University of Waterloo
microVAX II VMS 4.4

Username:

---

7. Enter your username. The response will be:

Password: XXXXXXXXXXXXXXXXXXXX

---

8. Enter your password. The response will be similar to the following:

Welcome to WATSUN-PV microVAX

Last interactive login on Thursday, 13-Nov-1987 10:06

Welcome to WATSUN-PV 2.0

University of Waterloo

Select?

The version and update number will be shown separated by a decimal point (e.g. 2.0).

The user is now in the WATSUN thermal program environment. To use the PV program, the user must first leave the thermal program by typing EXIT, and then enter the WATSUN-PV environment by typing PV. The computer will respond with:

Welcome to WATSUN-PV 2.0

University of Waterloo

Select?

The sample session (Section 1.5) provides an excellent example of a typical session. The user is encouraged to step through this session as it demonstrates the use of the commands that are used most often.

1.1.2 DATAPAC Access Refused

If after entering the WATSUN microVAX Sytek address (33500195), the computer responds with:

DATAPAC: CALL CLEARED - REMOTE DIRECTIVE

or:

DATAPAC: CALL CLEARED - DESTINATION NOT RESPONDING

the call from DATAPAC did not connect to the WATSUN microVAX computer system. It may mean that all the lines are busy or that the system is down. In both cases, try again later (usually a half hour is sufficient).

1.2 Running WATSUN-PV on a microComputer

After following the installation instructions which accompanied the program diskettes, simply change the directory on your hard disk to the directory which contains the WATSUN-PV program and type PV. For instance, if you installed the program diskettes onto a directory called WATSUN, type CD WATSUN to change the current directory to WATSUN and type PV to start the program.

1.3 WATSUN-PV Tutorial

This section uses a sample session of WATSUN-PV 2.0 to demonstrate the basic steps required in creating and running a WATSUN-PV simulation. The sample session and its accompanying descriptions are intended to illustrate the new aspects of WATSUN-PV as well as to aid the inexperienced user in utilizing the program.

1.3.1 Sample Session

The sample session provides examples on the following areas:

(a) Logon

(b) Command Usage

(c) Saving Changes to the SABB Data File

(d) Editing the Array Specification

(e) Saving Changes to the ARRA Data File

(f) Editing the Battery Specification

(g) Saving Changes to the BATT Data File

(h) Editing the Load Specification

(i) Entering Profiles

(j) Saving Changes to the LOAD Data File

(k) Running a Simulation

(l) Logoff

Throughout the sample session, all user entries will be designated by a ">" in the left hand margin (pressing the RETURN key will be shown as "<R>"). All computer responses will be shown as they appear on the terminal.

a) Logon

i) Logon to WATSUN Simulation Laboratory Computer

In order to use WATSUN-PV, it is necessary to access the WATSUN microVAX computer, through the DATAPAC network. See section 1.1 Logon Procedures. By following the instructions detailed in section 1.1, access to the WATSUN computer may be obtained. This section begins at the point when the WATSUN microVAX gives the following response:

Welcome to WATSUN-PV 2.0
University of Waterloo

Select?

---

ii) Starting WATSUN-PV on a microComputer

After ensuring that the current directory contains the WATSUN-PV program, type PV. The response should be similar to the following:

Welcome to WATSUN-PV 2.0
University of Waterloo

Select?

---

b) Command Usage

Once the user is at the point shown above (the "Select?" prompt has been received), the WATSUN-PV program has been accessed, and the user is being prompted to "select" a WATSUN-PV command. To obtain a list of the available WATSUN-PV commands, press RETURN in response to the "Select?" prompt. This may be done at any time when this prompt is displayed. The program will respond with the following command list:

Select one of the options and enter
Edit Run Print ERase Update Mail*
Help List LCity Type EXit

A more detailed description of each command may be obtained by entering the "HELP" command and pressing return. The following response is given:

Also try: HELP HELP

Following is a brief explanation of main level commands:

Edit	Create or modify a DATA file
Run	Executes WATSUN simulation using a DATA file
Print	Prints LISTING file at Waterloo
Update	Lists changes made to this version of WATSUN
*Mail	Sends/reads electronic mail to/from the WATSUN Simulation Laboratory. Mail is only available on the MicroVax version of WATSUN.
ERase	Erases a DATA or LISTING file
Help	Provides syntax and usage information for specified command
List	Lists names of DATA and LISTING files
LCity	Lists city names for which weather data is available
Type	Types LISTING file on terminal
EXit	Exits from the interactive WATSUN program

Any truncation of the commands down to the minimum (shown in capital letters) is acceptable. To use the program, a DATA file must be provided. The program produces a LISTING file containing the results. Use PRINT or TYPE to examine contents of the ERROR file.

Select?

---

*The MAIL command is only available on the WATSUN Simulation Laboratory computer.

Since the "Select?" prompt is again issued, the WATSUN-PV program is awaiting a command entry.

A useful feature for the novice or infrequent user is the "HELP" library. To obtain information on the use of any of the "Select?" commands, the user needs only type in "HELP", followed by the command in question. This procedure is illustrated in the sample session, where information is requested for the "Edit" command. Note that although entering "HELP EDIT" is a valid command, the entry may be shortened by truncating the commands down to their minimum length. This minimum length is indicated in the command list obtained when RETURN is pressed in response to the "Select?" prompt. Only the capitalized part of the command need be entered. Thus, "HELP EDIT" may be truncated down to "H E", as shown below.

```
 Select?
h e
The EDIT command creates a new DATA file or modifies an existing
DATA file containing parameter values describing a solar energy
system, and has the form:

          Edit "dfn"

where "dfn" is the DATA file to be edited.

If "dfn" is omitted. the user is prompted for it.

If the specified DATA file name, "dfn", doesn't exist, the user
is asked to enter a system name or hit the RETURN key to see the list
of system modules currently available. Once a system name has been
entered, the computer prompts the user with "Command?", indicating
that he is now in the subcommand level where the system parameters
may be examined and/or modified.
If the subcommand level SAVE is issued, the data is saved in the
data file specified by "dfn"
```

If the specified DATA file name, "dfn", already exists, that file is edited. The user is asked whether or not he wants to change the system type, and if so, to input the new system name (ie. DHWA, POOL, etc.). Control is then transferred to the subcommand level where the system parameters may be examined and/or modified.
If the subcommand level SAVE is issued, the user is prompted whether to replace the existing file or not. If he chooses to not replace the file, he is prompted to enter a new name or hit RETURN to abort.

Thus the "Edit" command is used to edit a simulation file. The command is entered by typing "Edit" or just "E" in response to "Select?". This results in the following:

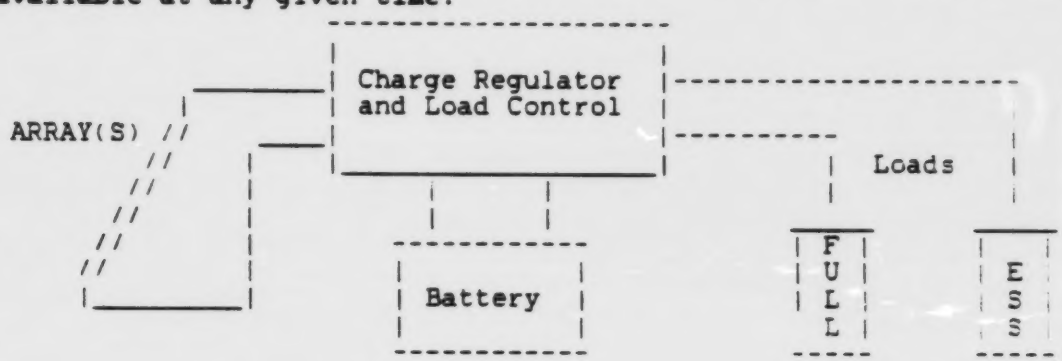
```
 Select?
e
 Enter the name of the data file you wish to edit:
simu
What type of file is to be edited?
     1 - General Simulation Data
     2 - Array Data
     3 - Battery Data
     4 - Load Data

1
 SIMU.DAT          is a new file.
 Do you wish to continue? RETURN=Yes/N=No


 Enter system name OR hit RETURN for list of systems


 Following systems are currently available under
 WATSUN interactive system

    SABB Stand Alone Battery Backup Photovoltaic System

 Enter system name OR hit RETURN for list of systems
sabb
```

Thus the systems available are listed, and the user is again prompted for the desired system name. In this case the Stand Alone Battery Backup Photovoltaic System has been selected. The program responds by querying if a system description is required, as shown below.

Require a system description? (Y=Yes/Return=No)
y

SABB Stand Alone Battery Backup Photovoltaic System

A typical stand alone battery backup photovoltaic system is shown below. The major components include the array, charge regulator, the batteries, load controller and the load. Radiation incident upon the array is converted to electric power which, via the charge regulator may be supplied to the load or be utilized to charge the batteries. Optionally, the load controller will switch between a full load and essential load depending on the amount of array and battery energy available at any given time.



Enter any character to continue, or
Enter MORE (to examine other systems) or EXIT

>a

Command? (Blocks Required: S R E).

As detailed in the system description, the Stand Alone Battery Backup system has three major components:

i) the Array (and regulator)
ii) the Battery
iii) the Load

Within the SABB data file, the regulator is specified along with the details of the simulation. In order to completely specify a photovoltaic system for the purpose of simulation, data files must be created, (by editing) data for each component. Hence the procedure detailed in the following pages shows the editing of the SABB, ARRA, BATT, and LOAD systems, thereby providing the necessary data for the Array, the Battery, and Load also. The specification of the Array, Battery, and Load in discrete data files allows the user, at RUN time, to "mix and match" components - a useful feature for design.
After the system description has been listed the user is given the options of examining other system descriptions by entering "MORE", or leaving the "Edit" command by typing "EXIT", or continuing with the creation of a data file. This third option is chosen by entering any character, in this case "a" has been selected, and pressing RETURN. The WATSUN-PV program then replies with the "Command?" prompt, as shown. This prompt indicates that the WATSUN-PV interactive program has been entered, and another set of commands are used here. To obtain a list of commands available, RETURN is pressed in response to the "Command?" prompt. The following list results:

```
Select one of the options and enter
    HELP   LIST   TITLe   SAVE   QUIT
    blockname<itemnumber <value>>
Most commands at "Select?" level will also work.
Data Blocks required for the SABB system are:
    S   R   E

Command?  (Blocks Required:  S  R  E  )
```

Again, entering "HELP" will give a more detailed list of the commands available, as shown below:

```
>help

Most commands which are possible at the "Select?" level are also possible
at the "Command?" level.
These commands are specific to the "Command?" level:
Command   Description
HELP      Display this list of command descriptions
LIST      Display contents of all required data blocks
TITLe     Enter or modify a title line
SAVE      Leave interactive program and save changes
QUIT      Leave interactive program without saving changes
blockname Display the specified data block
blockname itemnumber  Display the value of the specified item
blockname itemnumber value  Assign the specified value to the specified
          item
Data Blocks required for the SABB system are:
    S   R   E

Command?  (Blocks Required:  S  R  E  )
```

A detailed description of these commands is contained in section 2.6 Sub-command Descriptions. Note again that the part of the command name displayed above in capital letters indicates the minimum command truncation allowed for each command.

Often it is desirable to give the simulation a unique title; this will appear on the simulation output listing. In order to do so, the "TITLE" command must be issued:

```
>titl
   Enter a new title line, hit RETURN, or enter "Command?" level command
>WATSUN-PV DEMONSTRATION

 Command? (  Blocks Required:  S  R  E  )
```

Note that when the "HELP" command was issued, in response to the "Command?" prompt, a listing of the data blocks required for the simulation was given. These data blocks contain the input parameters which describe the solar system to be simulated. A listing of the contents of all the data blocks may be obtained by using the "LIST" command. Listings of individual data blocks may be obtained by entering the single letter name of the data block and pressing RETURN. A listing of an individual parameter within a data block may also be obtained by first specifying the name of the block and then the number of the item to be listed.

Data block parameters are changed by first identifying the current data block. This is done by entering the data block name and pressing RETURN. This will list the data block parameters and tell the program that subsequent changes are to be made to that data block. Parameter changes can then be made by entering the data block parameter item number and the new parameter value. Any number of parameter changes may be included on one line. The current data block may also be changed on the same line that parameter changes are made. The following example names the "Simulation" data block as the current data block, changes item 1 of this data block (simulation

year) to 0 (for TMY weather data) and item 2 to 100 (simulation period). The subsequent "S" and "R" commands result in the listing of the "Simulation" and "Regulator" data blocks. This will also cause the "Regulator" data block to become the current data block.

```
 Command?  ( Blocks Required:  S  R  E  )
s 1 0 2 100 s r

S  Simulation Data
    Item                    Description                          Value      Units
    S1    Simulation Year (0 for TMY)..................... 0.00000      year
    S2    Simulation Period.............................. 100.000      days
    S3    Start Day Number (Jan 1=1, Feb 1 = 32, etc.).. 1.00000      day
    S4    Initial State of Charge........................ 100.000      %
    S5    Detailed Print Interval (No=0, 1=hour,etc).... 0.00000      hr
    S6    Starting Hour of Detailed Print (No=0, 1-24).. 0.00000      hr
    S7    Detailed Analysis Period - Start Day.......... 0.00000      day
    S8                             - End Day............. 0.00000      day
    S9    Battery Temp Control (1=Fixed,2=Amb.,3=Min.).. 1.00000
    S10   Constant Battery Temperature................... 20.0000      C
    S11   Initial Battery Temperature.................... 20.0000      C
    S12   Relative Error Index (0 to 10)................ 3.00000
    S13   Maximum number of iterations.................. 10.0000
    S14   Economic Analysis Required (No=0, Yes=1)...... 0.00000

R  Control Data
    Item                    Description                          Value      Units
    R1    Array Control (1=MPPT, 2=Clamped, 3=None)..... 1.00000
    R2    MPPT efficiency................................ 95.0000      %
    R3    Reference Temp. for Maximum Charging Voltage.. 20.0000      C
    R4    Maximum Charging Voltage at Ref. Temp......... 14.3000      V
    R5    Voltage Temperature Coefficient............... 0.50000E-02 V/deg C
    R6    Trickle Charge Control (1=no, 2=yes).......... 1.00000
    R7    Parameter not used............................. 0.00000
    R8    Regulator Type (1=Series, 2=Shunt)............. 1.00000
    R9    Regulator Relay Current........................ 0.15000      Amps
```

Since the "Regulator" data block has been identified as the current data block, changes to its parameters may be made by entering the parameter item number and the parameter value. Thus, the following commands will alter the "Regulator" data block parameters 4, 5, and 1. The "R" command will cause the data block, with the changed parameters, to be listed.

```
 Command?  ( Blocks Required:  S  R  E  )
r 8 2 9 .25 1 2 r

R  Control Data
   Item                    Description                          Value      Units
   R1    Array Control (1=MPPT, 2=Clamped, 3=None)..... 2.00000
   R2    Parameter not used............................. 0.00000
   R3    Reference Temp. for Maximum Charging Voltage.. 20.0000      C
   R4    Maximum Charging Voltage at Ref. Temp......... 14.3000      V
   R5    Voltage Temperature Coefficient.............. 0.50000E-02 V/deg C
   R6    Trickle Charge Control (1=no, 2=yes).......... 1.00000
   R7    Parameter not used............................. 0.00000
   R8    Regulator Type (1=Series, 2=Shunt)............. 2.00000
   R9    Regulator Voltage Drop......................... 0.25000      V
```

It is also possible to issue commands to change parameters in several data blocks. The following command will change item 2 of the "simulation" data block and items 1, 4, and 5 of the "regulator" data block. It also lists the data blocks after the changes have been made.

```
 Command?  ( Blocks Required:  S  R  E  )
s 2 75 r 1 1 8 1 9 .15 s r

S  Simulation Data
   Item                    Description                          Value      Units
   S1    Simulation Year (0 for TMY)..................... 0.00000      year
   S2    Simulation Period.............................. 75.0000      days
   S3    Start Day Number (Jan 1=1, Feb 1 = 32, etc.).. 1.00000      day
   S4    Initial State of Charge........................ 100.000      %
   S5    Detailed Print Interval (No=0, 1=hour,etc).... 0.00000      hr
   S6    Starting Hour of Detailed Print (No=0, 1-24).. 0.00000      hr
   S7    Detailed Analysis Period - Start Day.......... 0.00000      day
   S8                             - End Day............. 0.00000      day
   S9    Battery Temp Control (1=Fixed,2=Amb.,3=Min.).. 1.00000
   S10   Constant Battery Temperature................... 20.0000      C
   S11   Initial Battery Temperature................... 20.0000      C
   S12   Relative Error Index (0 to 10)................ 3.00000
   S13   Maximum number of iterations.................. 10.0000
   S14   Economic Analysis Required (No=0, Yes=1)...... 0.00000

R  Control Data
   Item                    Description                          Value      Units
   R1    Array Control (1=MPPT, 2=Clamped, 3=None)..... 1.00000
   R2    MPPT efficiency................................ 95.0000      %
   R3    Reference Temp. for Maximum Charging Voltage.. 20.0000      C
   R4    Maximum Charging Voltage at Ref. Temp......... 14.3000      V
   R5    Voltage Temperature Coefficient.............. 0.50000E-02 V/deg C
   R6    Trickle Charge Control (1=no, 2=yes)......... 1.00000
   R7    Parameter not used............................ 0.00000
   R8    Regulator Type (1=Series, 2=Shunt)............ 1.00000
   R9    Regulator Relay Current....................... 0.15000      Amps
```

c) **Saving Changes to the SABB Data File**

Once all changes have been made to the Simulation and Regulator (and, optionally, Economic) parameters, it is necessary to incorporate the changes into a data file. This is achieved by issuing the "SAVE" command in response to the "Command?" prompt. As illustrated in a later example, it can also be issued in response to the "Profile?" prompt. The user will automatically be returned to the "Select?" command level when "SAVE" is issued. If the

user types "QUIT" or any of the "Select?" level commands (such as "RUN TORO" or "EXIT") in response to the "Command?" prompt, the program will ask if the data should be saved. If the user says "No" or hits RETURN, the new data will be discarded and the program will move to the "Select?" level. If a "Select?" level command was issued, it will be executed. The following example illustrates the use of the "SAVE" command:

```
>save
Output saved to SIMU.DAT

Select?
```

The following example illustrates the use of "QUIT" to escape from the "Command?" level without saving new data:

```
>quit

Do you wish to save the changes you have made?  (Y=yes/Return=No)
>

Select?
```

---

d) Editing the Array Specification

An array specification file must now be specified. The procedure to do this is similar to the previous section. First we begin by entering edit mode. In this case we wish to use a different file name - say ARRA.

```
 Select?
e arra
What type of file is to be edited?
     1 - General Simulation Data
     2 - Array Data
     3 - Battery Data
     4 - Load Data

2
 ARRA.ARR          is a new file.
 Do you wish to continue? RETURN=Yes/N=No


 Require a system description? (Y=Yes/Return=No)
y
    ARRA Array Specification
The solar array is represented by an equation representing
the energy balance on the panels.

 Command?  ( Blocks Required:  A  D  )
```

Typing A, the first array data block can be displayed, revealing the parameters available for input. Following that, the command to change the first parameter value to 10 is issued, so that each array module contains 10 panels.

```
 Command?  ( Blocks Required:  A  D  )
a

A  Array Data
   Item                    Description                          Value      Units
   A1    Number of Series Groups in Parallel..... 1.00000
   A2    Number of Modules in Series..... 1.00000
   A3    Area per Module..... 0.50000      m2
   A4    Tracking Method (1=no,2 axis,3=1 axis,4=azmt). 1.00000
   A5    Collector Slope..... 60.0000      deg.
   A6    Collector Azimuth (0=to equator,+=west)..... 0.00000      deg.
   A7    Reference Array Operating Temperature..... 20.0000      C
   A8    Reference Insolation Level..... 1000.00      W/m2
   A9    Reference MPP Voltage..... 16.0000      V
   A10   Reference MPP Current..... 4.50000      Amps
   A11   Reference Open Circuit Voltage..... 19.0000      V
   A12   Reference Short Circuit Current..... 4.80000      Amps
   A13   Array Lead-in resistance..... 0.00000      Ohms

 Command?  ( Blocks Required:  A  D  )
1 10

 Command?  ( Blocks Required:  A  D  )
```

e) Saving Changes to the ARRA Data File

Once all the changes have been made to the Array Specification parameters, it is necessary to incorporate the changes into a data file. This is achieved by issuing the "SAVE" command in response to the "Command?" prompt. The user can also quit without saving, as outlined in part c) of this section. The following example illustrates how this file would be saved:

```
Command?

>save

Output saved to ARRA.ARR

Select?
```

f) Editing the Battery Specification

A battery specification file must be used as well. The parameters in a battery file are based on test results provided by either the battery manufacturer, the user, or the ORTECH laboratory in Mississauga. The program is quite sensitive to the input data on the batteries. For example, if data points for the gasing region of the battery are unevently spaced and the battery is significantly gased during the simulation, inaccurate results may occur. It is best to consult the WATSUN lab if a user is creating a new battery file for the first time.

```
 Select?
e batt
What type of file is to be edited?
     1 - General Simulation Data
     2 - Array Data
     3 - Battery Data
     4 - Load Data

3
 BATT.BTR          is a new file.
 Do you wish to continue? RETURN=Yes/N=No


 Require a system description? (Y=Yes/Return=No)
y
    BATT Battery Specification
The lead-acid battery is represented by an equation relating the
battery voltage to the state of charge, operating current and
temperature.  This equation is tailored to each battery by a set
of parameters used to curve fit battery test data obtained by
cyclic charge-discharge tests at various temperatures and currents.


 Command?  ( Blocks Required:  B  C  G  D  )
```

```
b c g d

B  Battery Data
   Item                      Description                          Value      Units
   B1    Battery Type (0=Lead-Acid, 1=NiCd)..............  0.00000
   B2    Battery Capacity................................  85.0000      amp-hrs
   B3    Nominal Battery Voltage.........................  12.0000      V
   B4    Discharge Cut-off Voltage.......................  10.5000      V
   B5    Number of Cells per Battery.....................  6.00000

C  Charge Curve Data
   Item                      Description                          Value      Units
   C1    Number of Charge Curves Supplied................  5.00000
   C2    PROFILE:  Temp. and Current for Each Curve....
   C4    PROFILE:  Cell Voltage vs. Time for Curve 1...
   C6    PROFILE:  Cell Voltage vs. Time for Curve 2...
   C8    PROFILE:  Cell Voltage vs. Time for Curve 3...
   C10   PROFILE:  Cell Voltage vs. Time for Curve 4...
   C12   PROFILE:  Cell Voltage vs. Time for Curve 5...

G  Gasing Data
   Item                      Description                          Value      Units
   G1    20-Hour Charge Current..........................  3.60000      Amps
   G2    PROFILE:  Gasing Current vs (V - Vg).........

D  Discharge Curve Data
   Item                      Description                          Value      Units
   D1    Number of Discharge Curves Supplied.............  5.00000
   D2    PROFILE:  Temp. and Current for Each Curve....
   D4    PROFILE:  Cell Voltage vs. Time for Curve 1...
   D6    PROFILE:  Cell Voltage vs. Time for Curve 2...
   D8    PROFILE:  Cell Voltage vs. Time for Curve 3...
   D10   PROFILE:  Cell Voltage vs. Time for Curve 4...
   D12   PROFILE:  Cell Voltage vs. Time for Curve 5...

 Command?  ( Blocks Required:  B  C  G  D  )
```

---

g) Saving Changes to the BATT Data File

Once all the changes have been made to the Battery Specification parameters, it is necessary to incorporate the changes into a data file. This is achieved by issuing the "SAVE" command in response to the "Command?" prompt. The user can also quit without saving, as outlined in part c) of this section. The following example illustrates how this file would be saved:

Command?

>save

Output saved to BATT.BTR

Select?

---

h) Editing the LOAD Specification

The LOAD specification may now be entered. Again, EDIT is invoked to edit a file called LOAD.

```
 Select?
e load
What type of file is to be edited?
     1 - General Simulation Data
     2 - Array Data
     3 - Battery Data
     4 - Load Data

4
 LOAD.LOD          is a new file.
 Do you wish to continue? RETURN=Yes/N=No


 Require a system description? (Y=Yes/Return=No)
y
    LOAD Load Specification
The load consists of two types of demand - convenience load and
essential load. The full load is the sum of the convenience and
essential load. The user describes the load in terms of the full
and essential components, represented by two profiles, on for
weekdays, and one for weekends. The number of "weekdays" and days
in the "weekend" may be specified. The full load is the normal load
that the systems would be required to supply. The essential load is
that fraction of the full load deemed "essential". In the event that
the system cannot meet the full load it will attempt the essential
load. The essential load specified should not be greater than the
full load specified for any hour.
```

To examine the parameters of the only data block required, type "L".

```
 Command?  ( Blocks Required:  L  )
1

L  Load Data
     Item                    Description                          Value      Units
     L1    Load Voltage (nominal)..........................  12.0000      V
     L2    Type of Load (1=current, 2=power).............  2.00000
     L3    Minimum Load Voltage (LVD function).............  11.7000      V
     L4    Battery-to-Load Lead Resistance................  0.00000      Ohms
     L5    Essential Load Delivery? (1=yes, 0=no).........  1.00000
     L6    Number of Days in "weekdays"....................  7.00000      days
     L7    Number of Days in "week"........................  7.00000      days
     L8    Maximum Essential Load for "weekdays".........  0.00000      AMPS (W)
     L9    Maximum Essential Load for "weekends".........  0.00000      AMPS (W)
     L10   Maximum Full Load for "weekdays"..............  100.000      AMPS (W
     L11   Maximum Full Load for "weekends"..............  0.00000      AMPS (W
     L12   PROFILE: Essential Load Fraction - "weekdays".
     L13   PROFILE: Essential Load Fraction - "weekend"..
     L14   PROFILE: Total Load Fraction - "weekdays".....
     L15   PROFILE: Total Load Fraction - "weekends".....
     L16   PROFILE: Monthly load scale factors...........
```

In this data block there are 11 single value parameters and 5 Profiles. The single value parameters will be left unchanged, but part i) will show how to make changes to a profile.

i) <u>Entering Profiles</u>

A profile, in the WATSUN-PV program, is a data block parameter value which requires more than one value. For example, the electrical load varies throughout the day and requires a profile of 24 values, one for each hour of the day. In the block called "Load Data", the total load fraction changes throughout the day. Thus, item number 12 of the "Load Data" block is indicated to be a profile for the total load fraction. This block is displayed below.

Values for profiles may be displayed or modified by simply typing their

blockname and item number. In this case, the block has already been identified, above, as "L", so all that is needed is the parameter's item number, which is 12.

```
 Command?  ( Blocks Required:  L  )
12
   L12  PROFILE: Essential Load Fraction - "weekdays".fraction

   Code Value  Code Value  Code Value  Code Value  Code Value  Code Value

     1  1.00     2  0.00     3  0.00     4  0.00     5  0.00     6  0.00
     7  1.00     8  0.00     9  0.00    10  0.00    11  0.00    12  0.00
    13  1.00    14  0.00    15  0.00    16  0.00    17  0.00    18  0.00
    19  1.00    20  0.00    21  0.00    22  0.00    23  0.00    24  0.00

   Sum of elements in the profile is   4.00

 Profile?
```

Specific values in the profile may be altered by specifying the appropriate profile code number and the required new value(s). Thus the following command

changes profile items 7, 18, and 21, and subsequently displays the profile. The DISP command is used to display the full contents of the profile:

```
 Profile?
7 .75 18 .95 21 .75 disp
   L12  PROFILE: Essential Load Fraction - "weekdays".fraction

   Code Value  Code Value  Code Value  Code Value  Code Value  Code Value

     1  1.00     2  0.00     3  0.00     4  0.00     5  0.00     6  0.00
     7  0.75     8  0.00     9  0.00    10  0.00    11  0.00    12  0.00
    13  1.00    14  0.00    15  0.00    16  0.00    17  0.00    18  0.95
    19  1.00    20  0.00    21  0.75    22  0.00    23  0.00    24  0.00

   Sum of elements in the profile is   5.45
```

The value(s) of a specific profile code number may also be displayed, by simply typing the appropriate code number, as follows:

```
 Profile?
4
 Value for profile L12 item  4 is  0.0000000E+00
 Profile?
```

The "Profile?" prompt indicates that a profile command is required. A listing of available commands may be obtained by pressing RETURN in response to the "Profile?" prompt; the following list results:

```
Select one of the options and enter
    HELP    DISP    REPL    code v1 v2
Most commands at other levels will also work.

Profile?
```

A more detailed description of the available profile commands is obtained by entering the "HELP" command.

```
>help

Most commands which are possible at the "Command?" or "Select?" level are
also possible at the "Profile?" level. The following are the commands specific
to the "Profile?" level:
Command          Description
HELP             Display this list of command descriptions
DISP             Display the contents of the current profile
REPL             Replace all old profile values
code  <v1  <v2>> Display the values for the specified code number OR
                 Assign the given value 1 and value 2 to the specified
                 code number in a double-vector profile
                 (e.g. angle value = v1 and Akt value = v2)
```

Note: To escape the "Profile?" level, simply type a command intended for another level.

Profile?

Also see section 2.7 Profile Level Command Descriptions.

j) Saving Changes to the LOAD Data File

Once all changes have been made to the current profile, the user can return to one of the other levels of the program (the "Command?" or "Select?" level) by simply typing a command appropriate to another level. A blockname, such as "L", will work. In the example shown below, "SAVE" is typed, which is a "Command?" level command, discussed in the following section.

```
>save
Output saved to LOAD.LOD

Select?
```

---

k) Running a Simulation

A WATSUN-PV simulation may be run by issuing the "Run <cfn <dfn <<#>afn <<#>bfn <<#>lfn >>>>>" command, where cfn is the city weather file to be used, dfn is the name of the simulation data file, afn is the name of the array data file, bfn is the battery data file, and lfn is the load data file to be used. The symbol "#" is an integer multiplier for the appropriate data file, to indicate the number of arrays, batteries, or loads to be used. If it is omitted, the default value is 1. Thus, to run the simulation for the data files just created, for the city of Toronto, the following command is issued:

```
 Select?
R TORO SIMU 1ARRA 100BATT LOAD

                    SIMULATION DATA FILE NAME: SIMU
                        ARRAY DATA FILE NAME: ARRA
                      BATTERY DATA FILE NAME: BATT
                         LOAD DATA FILE NAME: LOAD
                            NUMBER OF ARRAYS:      1
                          NUMBER OF BATTERIES:    100
                                LOAD MULTIPLE:      1


SABB  TMY  TORONTO, ONT.              WATSUN-PV 2.0  1990 01 17 12:10:28
WATSUN-PV DEMONSTRATION

Processing weather data.....
     Day  10
     Day  20
     Day  30
     Day  40
     Day  50
     Day  60
     Day  70

.....Simulation begins.....
```

*** ENERGY ANALYSIS SUMMARY ***

MONTH	INCIDENT RADIATION (MWh)	AVAILABLE ARRAY OUTPUT (MWh)	BATTERY ENERGY INPUT (MWh)	BATTERY ENERGY OUTPUT (MWh)	TOTAL WIRING LOSSES (MWh)	ENERGY WASTED (MWh)	ENERGY DELIVERED (MWh)	TOTAL FRACTION DELIVERED
JAN	0.412	0.055	0.007	0.010	0.000	0.045	0.012	1.000
FEB	0.473	0.064	0.008	0.009	0.000	0.053	0.011	1.000
MAR	0.371	0.050	0.005	0.004	0.000	0.044	0.006	1.000
TOT	1.256	0.169	0.020	0.023	0.000	0.142	0.030	1.00

The result of the "RUN" command is a simulation output listing file with the same name as the main simulation DATA file. For example, since the first DATA file used for the "RUN" command was SIMU.DAT, the simulation output file would be called SIMU.LIS.

The output listing file may be displayed at the user's terminal using the "Type <fn>" command, where fn is the name of the listing file to be displayed.

```
**************************************
*                                    *
*                                    *
*                                    *
*          WATSUN-PV 2.0             *
*                                    *
*                                    *
*                                    *
*      UNIVERSITY OF WATERLOO        *
*          DECEMBER 1989             *
*                                    *
*                                    *
*                                    *
**************************************
```

DEVELOPED BY:

THE SYSTEMS DESIGN ENERGY GROUP
DEPARTMENT OF SYSTEMS DESIGN ENGINEERING

```
SIMULATION DATA FILE NAME: SIMU
     ARRAY DATA FILE NAME: ARRA
   BATTERY DATA FILE NAME: BATT
      LOAD DATA FILE NAME: LOAD
         NUMBER OF ARRAYS:        1
      NUMBER OF BATTERIES:      100
            LOAD MULTIPLE:        1
```

WATSUN-PV DEMONSTRATION

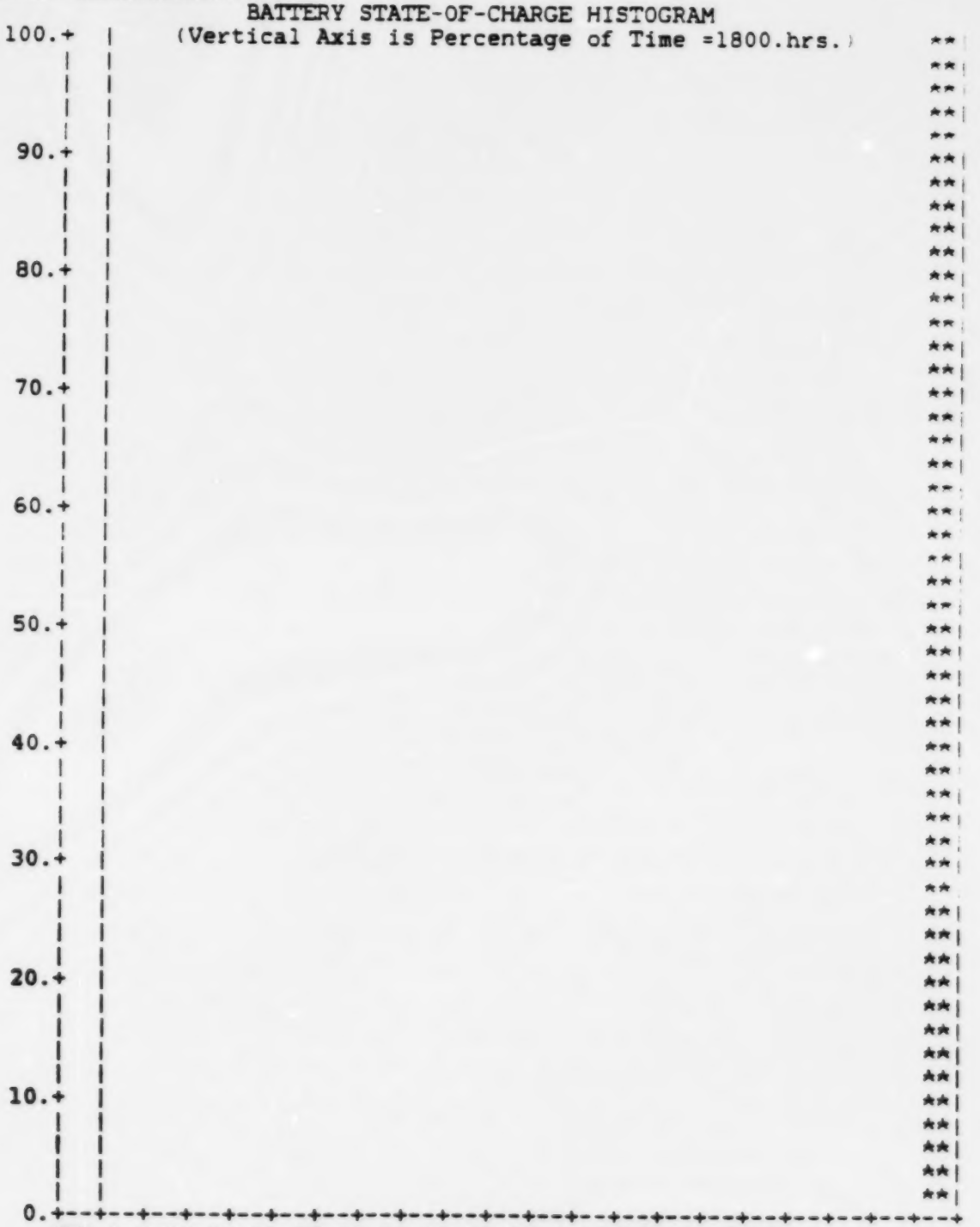
``BB TMY TORONTO, ONT. WATSUN-PV 2.0 1990 01 17 20:02:30
ISUN-PV DEMONSTRATION

****
* ENERGY ANALYSIS SUMMARY *
****

MONTH	INCIDENT RADIATION (MWh)	AVAILABLE ARRAY OUTPUT (MWh)	BATTERY ENERGY INPUT (MWh)	BATTERY ENERGY OUTPUT (MWh)	TOTAL WIRING LOSSES (MWh)	ENERGY WASTED (MWh)	ENERGY DELIVERED (MWh)	TOTAL FRACTION DELIVERED
JAN	0.412	0.055	0.007	0.010	0.000	0.045	0.012	1.000
FEB	0.473	0.064	0.008	0.009	0.000	0.053	0.011	1.000
MAR	0.371	0.050	0.005	0.004	0.000	0.044	0.006	1.000
TOT	1.256	0.169	0.020	0.023	0.000	0.142	0.030	1.000

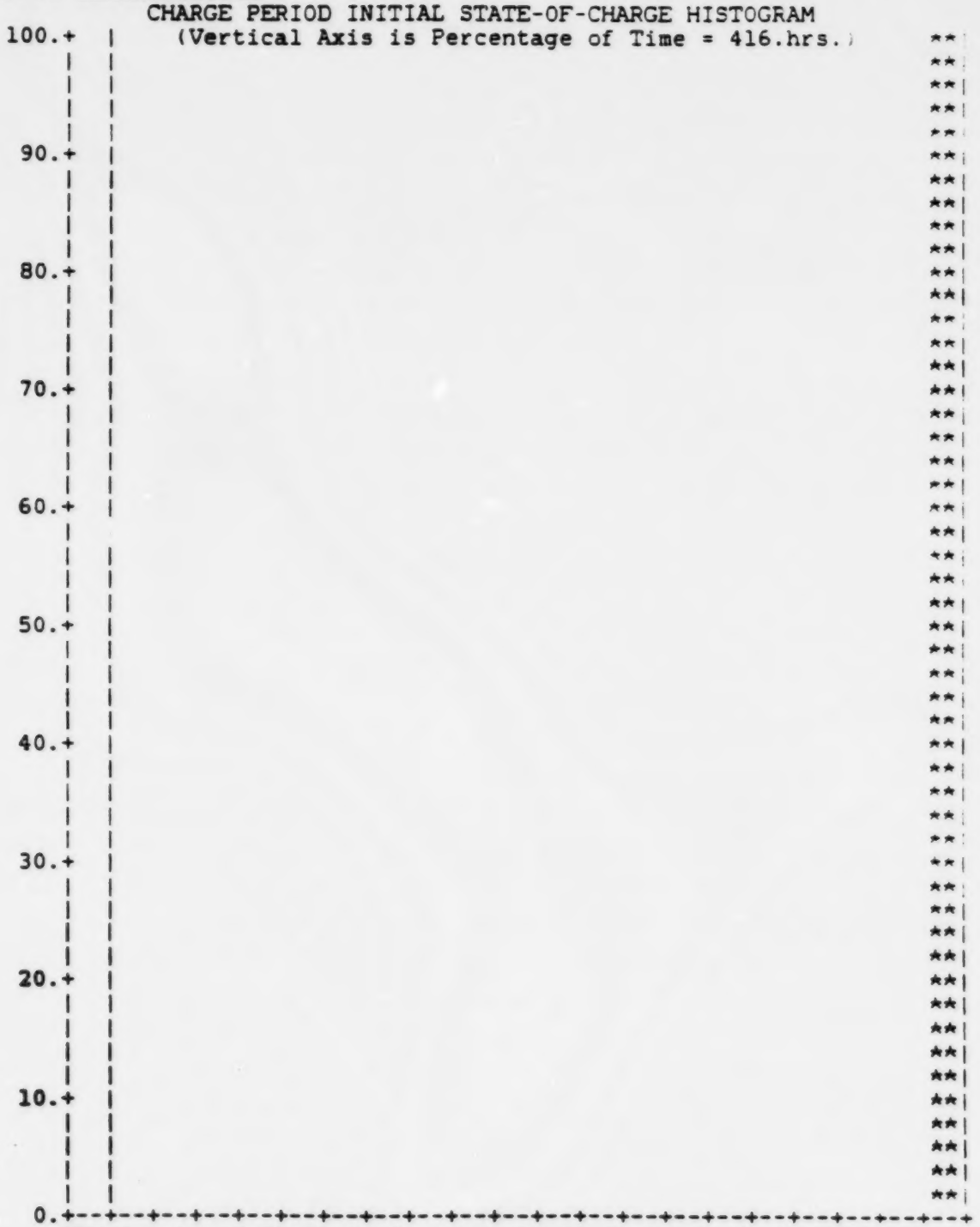
SABB TMY TORONTO, ONT. WATSUN-PV 2.0 1990 01 17 19:38:08
WATSUN-PV DEMONSTRATION

BATTERY STATE-OF-CHARGE HISTOGRAM



SABB TMY TORONTO, ONT. WATSUN-PV 2.0 1990 01 17 19:38:08
TSUN-PV DEMONSTRATION

CHARGE PERIOD INITIAL STATE-OF-CHARGE HISTOGRAM
(Vertical Axis is Percentage of Time = 416.hrs.)



(0) (0) (0) (0) (0) (0) (0) (0) (0) (0) (100)
(0) (0) (0) (0) (0) (0) (0) (0) (0) (0)

SABB TMY TORONTO, ONT. WATSUN-PV 2.0 1990 01 17 19:38:08
WATSUN-PV DEMONSTRATION

TABLE OF CONSECUTIVE HOURS SYSTEM IS "DOWN"

PERIOD LENGTH [hrs]	FAILURE TO MEET LOAD [number of occurrences] ESSENTIAL	FULL
SYSTEM ABLE TO MEET LOAD REQUIREMENTS FOR ENTIRE SIMULATION PERIOD		
TOTAL	0	0

	TOTAL HOURS OF LOAD DEMAND THIS SIMULATION PERIOD ESSENTIAL	FULL
	0	300
LOSS-OF-LOAD PROBABILITY	0.0000	0.0000

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Simulation Data

1	Simulation Year (0 for TMY).....	0.00000	year
2	Simulation Period.....	75.0000	days
3	Start Day Number (Jan 1=1, Feb 1 = 32, etc.)..	1.00000	day
4	Initial State of Charge.....	100.000	%
5	Detailed Print Interval (No=0, 1=hour,etc)....	0.00000	hr
6	Starting Hour of Detailed Print (No=0, 1-24)..	0.00000	hr
7	Detailed Analysis Period - Start Day.....	0.00000	day
8	- End Day.....	0.00000	day
9	Battery Temp Control (1=Fixed,2=Amb.,3=Min.)..	1.00000	
10	Constant Battery Temperature.....	20.0000	C
11	Initial Battery Temperature.....	20.0000	C
12	Relative Error Index (0 to 10).....	3.00000	
13	Maximum number of iterations.....	10.0000	
14	Economic Analysis Required (No=0, Yes=1).....	0.00000	

Control Data

1	Array Control (1=MPPT, 2=Clamped, 3=None).....	1.00000	
2	MPPT efficiency.....	95.0000	%
3	Reference Temp. for Maximum Charging Voltage..	20.0000	C
4	Maximum Charging Voltage at Ref. Temp.....	14.3000	V
5	Voltage Temperature Coefficient.....	0.50000E-02	V/deg C
6	Trickle Charge Control (1=no, 2=yes).....	1.00000	
7	Parameter not used.....	0.00000	
8	Regulator Type (1=Series, 2=Shunt).....	1.00000	
9	Regulator Relay Current.....	0.15000	Amps

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Array Data

1	Number of Series Groups in Parallel.....	10.0000	
2	Number of Modules in Series.....	1.00000	
3	Area per Module.....	0.50000	m2
4	Tracking Method (1=no,2 axis,3=1 axis,4=azmt).	1.00000	
5	Collector Slope.....	60.0000	deg.
6	Collector Azimuth (0=to equator,+=west).....	0.00000	deg.
7	Reference Array Operating Temperature.....	20.0000	C
8	Reference Insolation Level.....	1000.00	W/m2
9	Reference MPP Voltage.....	16.0000	V
10	Reference MPP Current.....	4.50000	Amps
11	Reference Open Circuit Voltage.....	19.0000	V
12	Reference Short Circuit Current.....	4.80000	Amps
13	Array Lead-in resistance.....	0.00000	Ohms

Detailed Array Data

1	Alpha.....	0.25000E-02	1/C
2	Beta.....	0.50000	
3	Gamma.....	0.29000E-02	1/C
4	Front Panel.....Solar Absorptance.....	0.10000	
5	.....Emissivity.....	0.95000	
6	.....Transmittance (visible).....	0.95000	
7	.....Transmittance (infrared).....	0.90000	
8	Back Panel.....Emissivity.....	0.90000	
9	PROFILE: Incidence Angle Modifiers (Vert.)...		

Angle Values..... degrees

0.000	30.000	45.000	60.000	90.000

Akt Values..... unitless

1.000	1.000	0.970	0.877	0.000

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Battery Data

1	Battery Type (0=Lead-Acid, 1=NiCd).....	0.00000	
2	Battery Capacity.....	85.0000	amp-hrs
3	Nominal Battery Voltage.....	12.0000	V
4	Discharge Cut-off Voltage.....	10.5000	V
5	Number of Cells per Battery.....	6.00000	

Charge Curve Data

1	Number of Charge Curves Supplied.....	5.00000			
2	PROFILE: Temp. and Current for Each Curve....				
	Temperature Values for Each Curve..... Celsius				
	20.000	20.000	20.000	-20.000	-40.000
	Current Values for Each Curve..... Amps				
	3.600	1.060	0.100	1.060	1.060
4	PROFILE: Cell Voltage vs. Time for Curve 1...				
	Time..... hours				
	0.000	18.000	19.000	20.000	22.000
	Voltage..... V				
	2.030	2.200	2.250	2.300	2.550
6	PROFILE: Cell Voltage vs. Time for Curve 2...				
	Time..... hours				
	0.000	72.000	76.000	80.000	84.000
	Voltage..... V				
	2.010	2.170	2.230	2.300	2.400
8	PROFILE: Cell Voltage vs. Time for Curve 3...				
	Time..... hours				
	0.000	980.000	983.000	986.000	990.000
	Voltage..... V				
	2.000	2.250	2.251	2.252	2.254
10	PROFILE: Cell Voltage vs. Time for Curve 4...				
	Time..... hours				
	0.000	72.000	76.000	80.000	84.000
	Voltage..... V				
	2.010	2.400	2.460	2.530	2.630
12	PROFILE: Cell Voltage vs. Time for Curve 5...				
	Time..... hours				
	0.000	72.000	76.000	80.000	84.000
	Voltage..... V				
	2.010	2.500	2.560	2.630	2.730

Gasing Data

1	20-Hour Charge Current.....	3.60000	Amps
2	PROFILE: Gasing Current vs (V - Vg).....		
	Voltage Differential Above Initial Gasing.. V		
	0.000	0.200	0.300	0.400	0.500
	Gasing Current wrt. 20-Hour Charge Rate.... I-20				
	0.000	0.139	0.278	1.250	2.417

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Discharge Curve Data
---

1 Number of Discharge Curves Supplied..... 5.00000
2 PROFILE: Temp. and Current for Each Curve....
Temperature Values for Each Curve..... Celsius
20.000 20.000 20.000 -20.000 -40.000
Current Values for Each Curve..... Amps
3.600 1.060 0.100 1.060 1.060
4 PROFILE: Cell Voltage vs. Time for Curve 1...
Time..... hours
0.000 11.800 15.600 18.200 20.000
Voltage..... V
2.100 2.020 1.975 1.920 1.751
6 PROFILE: Cell Voltage vs. Time for Curve 2...
Time..... hours
0.000 47.200 62.400 72.800 80.000
Voltage..... V
2.100 2.020 1.975 1.920 1.751
8 PROFILE: Cell Voltage vs. Time for Curve 3...
Time..... hours
0.000 566.400 748.800 873.600 960.000
Voltage..... V
2.100 2.020 1.980 1.920 1.800
10 PROFILE: Cell Voltage vs. Time for Curve 4...
Time..... hours
0.000 28.300 37.400 43.700 48.000
Voltage..... V
2.050 2.010 1.980 1.960 1.751
12 PROFILE: Cell Voltage vs. Time for Curve 5...
Time..... hours
0.000 18.800 24.900 29.100 32.000
Voltage..... V
2.030 2.000 1.975 1.940 1.751

AD TMY TORONTO, ONT. WATSUN-PV 2.0 1990 01 17 19:38:08
...TSUN-PV DEMONSTRATION

Load Data

1	Load Voltage (nominal).....	12.0000	V
2	Type of Load (1=current, 2=power).....	2.00000	
3	Minimum Load Voltage (LVD function).....	11.7000	V
4	Battery-to-Load Lead Resistance.....	0.00000	Ohms
5	Essential Load Delivery? (1=yes, 0=no).....	1.00000	
6	Number of Days in "weekdays".....	7.00000	days
7	Number of Days in "week".....	7.00000	days
8	Maximum Essential Load for "weekdays".....	0.00000	AMPS (W
9	Maximum Essential Load for "weekends".....	0.00000	AMPS (W
10	Maximum Full Load for "weekdays".....	100.000	AMPS (W
11	Maximum Full Load for "weekends".....	0.00000	AMPS (W

12 PROFILE: Essential Load Fraction - "weekdays". fraction

1.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	0.00	0.95	1.00	0.00	0.75	0.00	0.00	0.00

13 PROFILE: Essential Load Fraction - "weekend".. fraction

1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

14 PROFILE: Total Load Fraction - "weekdays"..... fraction

1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

15 PROFILE: Total Load Fraction - "weekends"..... fraction

1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

16 PROFILE: Monthly load scale factors.....

1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

SABB TMY TORONTO, ONT. WATSUN-PV 2.0 1990 01 17 19:38:08
WATSUN-PV DEMONSTRATION

DISCHARGE CURVE INPUT DATA, WITH SOC:
TIME [HOURS], VOLTAGE [VOLTS], AND SOC []

TEMP(1) = 20.0 C, CURRENT(1) = -3.60 AMPS, CAPACITY:					72.03 A-HR	
TIME:	0.00	11.80	15.60	18.20	20.00	20.01
VOLTAGE:	2.10	2.02	1.98	1.92	1.75	1.75
CHARGE:	1.0000	0.4102	0.2203	0.0903	0.0004	0.0000
TEMP(2) = 20.0 C, CURRENT(2) = -1.06 AMPS, CAPACITY:					84.83 A-HR	
TIME:	0.00	47.20	62.40	72.80	80.00	80.03
VOLTAGE:	2.10	2.02	1.98	1.92	1.75	1.75
CHARGE:	1.0000	0.4102	0.2203	0.0903	0.0004	0.0000
TEMP(3) = 20.0 C, CURRENT(3) = -0.10 AMPS, CAPACITY:					98.36 A-HR	
TIME:	0.00	566.40	748.80	873.60	960.00	983.57
VOLTAGE:	2.10	2.02	1.98	1.92	1.80	1.75
CHARGE:	1.0000	0.4241	0.2387	0.1118	0.0240	0.0000
TEMP(4) = -20.0 C, CURRENT(4) = -1.06 AMPS, CAPACITY:					50.89 A-HR	
TIME:	0.00	28.30	37.40	43.70	48.00	48.01
VOLTAGE:	2.05	2.01	1.98	1.96	1.75	1.75
CHARGE:	1.0000	0.4106	0.2210	0.0898	0.0003	0.0000
TEMP(5) = -40.0 C, CURRENT(5) = -1.06 AMPS, CAPACITY:					33.93 A-HR	
TIME:	0.00	18.80	24.90	29.10	32.00	32.01
VOLTAGE:	2.03	2.00	1.98	1.94	1.75	1.75
CHARGE:	1.0000	0.4127	0.2221	0.0909	0.0003	0.0000

CHARGE CURVE INPUT DATA, WITH SOC:
TIME [HOURS], VOLTAGE [VOLTS], AND SOC []

TEMP(1) = 20.0 C, CURRENT(1) = 3.60 AMPS, CAPACITY:					72.03 A-HR	
TIME:	0.00	18.00	19.00	20.00	22.00	22.13
VOLTAGE:	2.03	2.20	2.25	2.30	2.55	2.58
CHARGE:	-0.0590	0.8407	0.8840	0.9215	0.9989	1.0000
TEMP(2) = 20.0 C, CURRENT(2) = 1.06 AMPS, CAPACITY:					84.83 A-HR	
TIME:	0.00	72.00	76.00	80.00	84.00	86.13
VOLTAGE:	2.01	2.17	2.23	2.30	2.40	2.47
CHARGE:	0.0361	0.9358	0.9615	0.9680	0.9883	1.0000
TEMP(3) = 20.0 C, CURRENT(3) = 0.10 AMPS, CAPACITY:					98.36 A-HR	
TIME:	0.00	980.00	983.00	986.00	990.00	990.55
VOLTAGE:	2.00	2.25	2.25	2.25	2.25	2.25
CHARGE:	-0.0024	0.9940	0.9966	0.9986	1.0000	1.0000
TEMP(4) = -20.0 C, CURRENT(4) = 1.06 AMPS, CAPACITY:					50.89 A-HR	
TIME:	0.00	72.00	76.00	80.00	84.00	86.13
VOLTAGE:	2.01	2.40	2.46	2.53	2.63	2.70
CHARGE:	-0.6066	0.8930	0.9358	0.9466	0.9804	1.0000
TEMP(5) = -40.0 C, CURRENT(5) = 1.06 AMPS, CAPACITY:					33.93 A-HR	
TIME:	0.00	72.00	76.00	80.00	84.00	86.13
VOLTAGE:	2.01	2.50	2.56	2.63	2.73	2.80
CHARGE:	-1.4098	0.8396	0.9038	0.9199	0.9706	1.0000

1) Logoff

When the user has finished with WATSUN-PV, it is necessary to exit the program and logoff the system. This is accomplished by issuing the "EXIT LOG" command. This will result in a message from the system, as shown below.

```
Select?
>exit
Bye!
>log
 USERNAME logged out at 13-Nov-1988 13:56:25.60
```

---

2 WATSUN-PV Program Structure and Command Descriptions

In order to use WATSUN, it is not necessary to understand how the program works. However, by understanding the basic structure of the program, the user will have a more thorough appreciation of the consequences of a particular command. This understanding will enable the user to direct the program to accomplish the task at hand in the most efficient manner.

Two elements are used in the operation of WATSUN: files and programs. Files, as the name implies, are collections of information placed in a specific location and appropriately labeled. Programs are a series of explicit instructions which tell the computer what to do and when to do it. The files are used by the programs as input and output devices.

2.1 Files

Three types of files are used with the WATSUN program: DATA files, LISTING files, and weather files. A DATA file contains the parameters describing the solar system which the user wishes to simulate while the LISTING files contain the results of the simulation. The weather files contain all the meteorological data required by the WATSUN program.

The use of each of these files and the WATSUN program will be discussed in the following sections.

2.2 Programs

The WATSUN program is a single FORTRAN module, but is made up of 3 main components: a control program, an interactive program, and a simulation program.

The master program is the administrator for the other two programs. It manages the DATA, LISTING, and the weather files and takes care of all the interfacing between the interactive program and the simulation program.

The interactive program assists the user with the creation and modification of DATA files which will be used with the simulation program.

The simulation program performs the actual simulation of the solar system using the DATA file and the weather file specified by the user. This program produces the LISTING file containing the results of the simulation.

2.3 Program Architecture

This section examines the architecture of the program; the interaction between the various files and programs. Figure 2.3.1 illustrates this architecture and is a valuable aid to understanding the process behind the WATSUN commands.

The interactive program operates in the following manner. When the user enters an EDIT command for a file that exists, that file is used as input data to the interactive program. For example, if the user specifies EDIT TEST2, TEST2.DAT will be used as input data to the interactive program. If the file does not exist, the interactive program uses data from a permanent file called "PV20.WAT". This file contains the default values for all parameters. Once the old values of the parameters are read in, the user can manipulate the data using the interactive commands. When the user is satisfied with the data and leaves the interactive program, the data is placed in the file overwriting the old values, or the user can supply a new name for the data set. When the user enters the RUN command, the simulation program uses the data in the specified data file as well as the specified weather data file to perform the simulation. After the simulation has been completed, the results are placed in a listing file which bears the same name as the data file that was used. For example, if the input file was SAMPLE.DAT then the output file would be called SAMPLE.LIS. This output file can be typed to the screen using the TYPE command, or printer using the PRINT command, but the file will remain stored until the user specifically requests that it be erased by using the ERASE command. The echo of the input parameters,

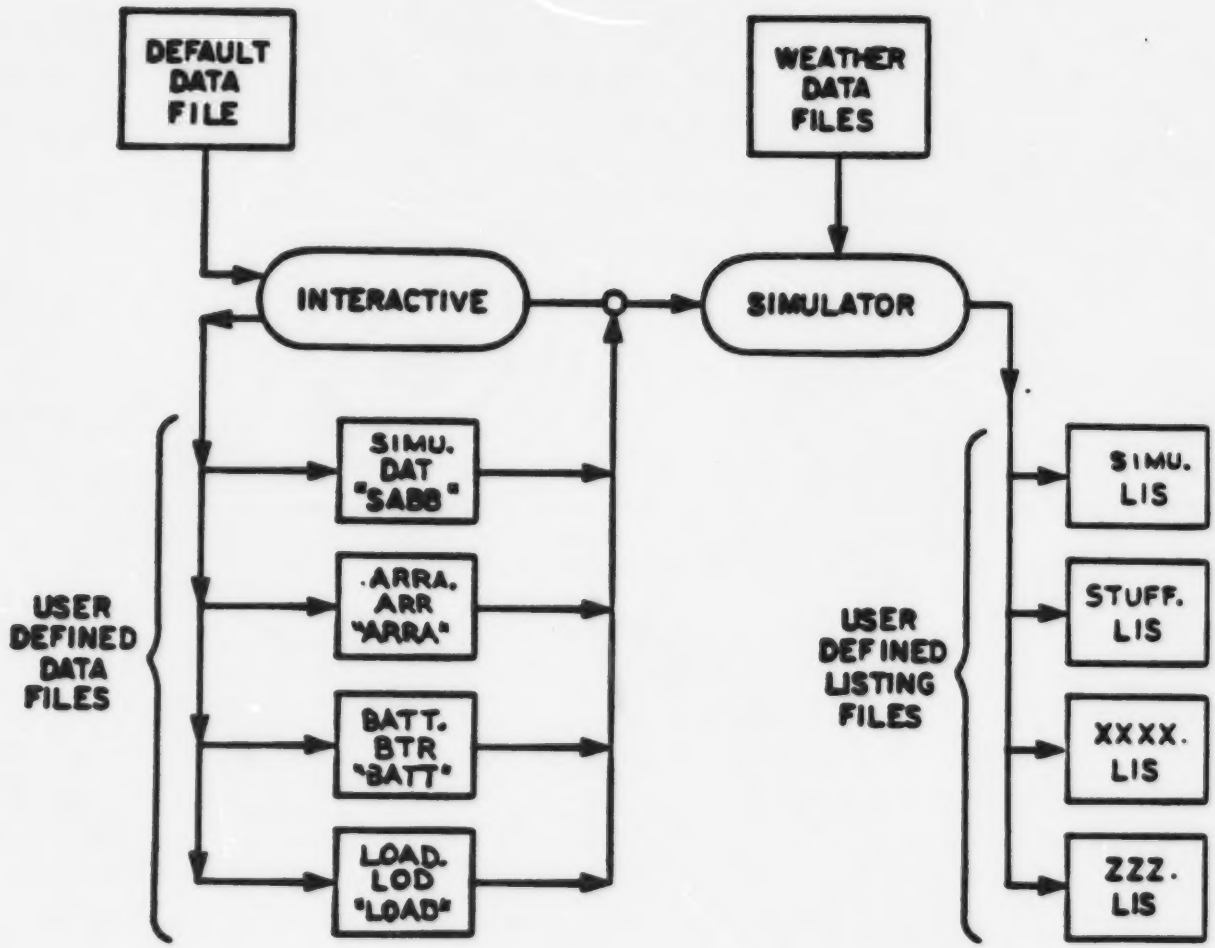


Figure 2.3.1 - WATSUN-PV Program Architecture

the discharge and charge curves with state-of-charge data, and any detailed hour by hour output, are also contained in a file called DETAILS.LIS, which can be typed or printed separately if desired.

2.4 General Command Structure

The WATSUN Program mediates between the user, the various files, and the actual WATSUN Simulation Program. It provides the user with three distinct levels of command:

(a) The Main Command Level (Select?):

The user enters this level when he "logs-on" to the computer (See Logon section 1.1 Procedures). At this level, the user has the ability to manipulate data and listing files and to run the simulation program. A menu of commands available at this level is displayed by pressing the RETURN key after the "Select?" prompt appears.

(b) The Subcommand Level (Command?):

The user enters this level by issuing an EDIT command at the main command (Select?) level. At this subcommand level, the user may modify the input data blocks used in the simulation. A description of available subcommands is displayed by pressing RETURN key after the "Command?" prompt appears.

(c) The Profile Command Level (Profile?):

The user enters this level when he types the blockname and item number of a profile at the subcommand (Command?) level. At the Profile level, the user may modify any data block items that required profiles. A menu of available Profile commands is displayed by pressing the RETURN key after the "Profile?" prompt appears.

Details of each command at the three command levels are given later. All command descriptions adhere to the following simple conventions:

(1) All command names may be truncated down to a minimum, which is shown in capital letters (ie. any lowercase letters are optional).

(2) Pointed brackets, <>, indicate that the option specified within the brackets may be omitted. The brackets themselves should not be typed as part of the command.

(3) A vertical line, |, indicates that only one of the options on either side of the line is to be used.

Example: XCOMmand < option1 < option2 | option3>>

Valid forms of the command are:

i) XCOM

ii) XCOMMAND option1

iii) XCOMMA option1 option2

iv) XCOM option1 option3

Invalid forms of the command are:

i) XCO

ii) XCOMMAND option2

iii) XCOM option2 option3

The command XCO is invalid because it is shorter than the allowed minimum, XCOM. The second example is invalid because "option1" is not specified.

In this case, the computer would mistake "option2" for "option1". The third example is invalid because both "option2" and "option3" are specified, but only one is allowed.

2.5 Command Descriptions

While in the main command level, the user is prompted by the word "Select?". This command level is designed to allow easy manipulation of WATSUN related files, and execution of the WATSUN simulation program. The following is a list of available main level commands:

Edit	Run	Print	ERase	Update	Mail
Help	List	LCity	Type	Exit	

NOTE: The MAIL command is only available on the WATSUN Simulation Laboratory computer.

2.5.1 EDIT Command

The EDIT command creates a new data file or modifies an existing data file containing parameter values describing a solar energy system, and has the form:

Edit "dfn"

where "dfn" is the data file to be edited. If "dfn" is omitted, the user is prompted for it.

In the PV system, the user is next prompted for the type of data file to be edited. There are four different data file types, each containing a different set of information for the system.

If the specified data file name, "dfn" doesn't exist, the user is asked to enter a system name or hit the RETURN key to see the list of system modules currently available. Once a system name has been entered, the computer prompts the user with "Command?", indicating that he is now in the subcommand level where the system parameters may be examined and/or modified.

If the subcommand level SAVE is issued, the data is saved in the data file specified by "dfn".

If the specified data file name, "dfn", already exists, that file is edited. If the file is a simulation data type of file, the user will be asked whether or not he wants to change the system name, and if so, to input the new system name (the only system supported by WATSUN-PV 2.0 is SABB, but this will change in the next version). Control is then transferred to the subcommand level where the system parameters may be examined and/or modified. The other types of data files, array, battery, and load, do not use different system names, so control is passed directly to the subcommand level.

If the subcommand level SAVE is issued, the user is prompted whether to replace the existing file or not. If he chooses not to replace the file, he is prompted to enter a new name or hit RETURN to abort.

2.5.2 RUN Command

The RUN command performs WATSUN-PV simulations, and has the form:

Run < cfn < dfn < <#> afn < <#> bfn < <#> lfn > > > > >

where "cfn" is the name of the city weather file to be used (see LCity)

"dfn" is the name of the simulation data file - the file would have a system type of "SABB" and a file extension ".dat"

"afn" is the name of the array data file - extension ".arr"

"bfn" is the name of the battery data file - extension ".btr"

"lfn" is the name of the load data file - extension ".lod"

The symbol "#" refers to the number of arrays, batteries, or loads to be used in the simulations. The number specified must be at least one (1). A missing number (#) parameter will be interpreted as one (1).

The order in which the filenames are specified is important. If a name is omitted, the program will prompt the user for the next file it expects. If files are specified out of order, or with, for example, an array filename missing, an error will result. The following examples illustrate the proper use of RUN command.

e.g. RUN TORO SIMU 12ARR 12CELL LOAD1

will perform the simulation using Toronto weather data, data with simulation from file SIMU.DAT, on a system with 12 arrays as specified by file ARR.ARR, 12 batteries as specified by the CELL.BTR file and a load as specified by the LOAD1.LOD file.

e.g. RUN OTTA SIMU 12ARRAY

will cause the program to prompt the user for the remaining filenames, and then proceed with the simulation:

```
 Select?
r otta simu 12array

 Enter BATTERY file name:
12batt

 Enter LOAD file name:
house

                    SIMULATION DATA FILE NAME: SIMU
                        ARRAY DATA FILE NAME: ARRAY
                     BATTERY DATA FILE NAME: BATT
                        LOAD DATA FILE NAME: HOUSE
                          NUMBER OF ARRAYS:       12
                       NUMBER OF BATTERIES:       12
                             LOAD MULTIPLE:        1

SABB  TMY  OTTAWA, ONT.                  WATSUN-PV 2.0  1990 01 17 18:45:2
WATSUN-PV DEMONSTRATION

Processing weather data.....
```

2.5.3 TYPE Command

The TYPE command displays the simulation results, contained in the specified listing file, on the terminal, and has the form:

Type < lfn >

where "lfn" is the name of the listing file to be displayed. If "lfn" is omitted, the user is prompted for a file name.

The terminal display is identical to the printout given by the PRINT command. It contains an echo of all input data, and tables that summarize energy quantities.

e.g. TYPE SYS2 will display the contents of the file called SYS2.LIS at the terminal.

2.5.4 PRINT Command

The PRINT command prints the simulation results contained in the specified listing file, and has the form:

Print < lfn >

where "lfn" is the name of the listing file to be printed. If "lfn" is omitted, the user is prompted for a file name.

If the user is logged onto the VAX, the results are printed at the WATSUN Simulation Laboratory. The printout, which contains an echo of all input data, and tables that summarize energy quantities, is identical to the terminal display produced by the TYPE command.

e.g. PRINT TEST will print the contents of the file called TEST.LIS

2.5.5 LIST Command

The LIST command lists the names of previously saved data and/or listing files, and has the form:

List < dft ! fn ft dft >

where "fn" is the file name

"ft" is the file type (data or listing)

"dft" is the data file type (array, battery, data, or load)

If "fn", "ft", and "dft" are entered, the computer simply verifies that the specified file exists, or states that it does not.

Note that all three parameters must be entered if the existence of a specific file is to be verified. In the case of listing files, no meaningful "dft" exists, so the user may enter any character as the third parameter.

If "fn" is omitted, then all existing file names of the type "ft" are listed. If "ft" is data files, and "dft" has been specified, only that subgroup of data files will be listed. If "ft" is also omitted, all existing data and listing file names are listed.

e.g. L will list all existing data and listing file names.

LIST DATA will list all existing array, battery, data, and load file names.

L LISTING will list all existing listing file names.

L D B will list all existing battery data file names.

L GEORGE D will verify the existence of file GEORGE.LOD.

L will verify the existence of file GEORGE.LIS.

L GEORGE L X

2.5.6 ERASE Command

The ERASE command erases a specified file, and has the form:

Erase < fn < ft < dft > > >

where "fn" is the file name

"ft" is the file type (data or listing)

"dft" is the data file type (array, battery, data, or load)

If "ft" is omitted, the user will be prompted for a file type. If the file type is Data, and "dft" is omitted, the user will be prompted for the data file type. If "fn", "ft", and "dft" are all omitted, the user will be prompted for all the required information.

The file to be erased must exist on the permanent storage disk as a result of the execution of the program or an earlier SAVE command. It is recommended that unwanted files be erased from time to time.

e.g. ERASE GEORGE LISTING will erase GEORGE.LIS from permanent storage.

ERASE DELCO D B will erase DELCO.BTR from permanent storage.

2.5.7 HELP Command

The HELP command provides syntax and usage information for the specified "commandname". This command has the form:

Help <commandname>

where "commandname" is one of the following:

Edit	Run	Print	ERase	Update	Mail
Help	List	LCity	Type	EXit	

e.g. HELP EDIT will cause information on the EDIT command to be displayed. (Could also use H EDIT, HELP E, HE, etc.).

If "commandname" is omitted, a brief description of all main level commands is given.

2.5.8 LCITY Command

The LCITY command lists the names or horizontal meteorological data files by city names, and has the form:

LCity < cfn >

where "cfn" is the four-character designation of the weather file for the city of interest (usually the first four letters of the city name, ie. OTTA for Ottawa.) If "CANA" or "U.S." is specified, the list of Canadian or U.S. cities for which weather data is available is displayed.

If "cfn" is specified, the computer simply verifies if data is available for that city. If "cfn" is omitted, the user is prompted for the city name.

e.g. LC OTTA will verify that weather data is available for Ottawa.

LCITY CANA will list all cities for which weather data is available in Canada.

2.5.9 UPDATE Command

The UPDATE command is used to examine recent changes to the WATSUN program, and has the form:

Update < ALL >

e.g. UPDATE will cause the latest modification to be displayed

U ALL will cause all modifications to the current version of WATSUN to be displayed.

2.5.10 MAIL Command

NOTE: The MAIL command is only available on the WATSUN Simulation Laboratory computer.

The MAIL command puts you in the Vax interactive mail utility. The commands can be abbreviated down to what is shown in capitals.

READING MAIL

Hitting return at the MAIL> prompt is equivalent to entering the REAd command

REAd	reads the next mail message
REAd/New	reads new mail messages
REAd n	reads mail message number n

SENDING MAIL

You can send mail with the Send command. Specify the user id of the recipient at the To: prompt. Send/All sends the last message you sent to a different person.

REPLYING TO MAIL

You can reply to a mail message with the Reply command. It is the same as Send except that the person the mail is sent to and the subject are automatically set.

LISTING MAIL MESSAGES

DIrectory gives you a list of all the mail files sent to you (in the current folder-more on folders in a minute), who sent them and the subject.

DELETING MESSAGES

Delete	deletes the current message
Delete/All	deletes all messages
Delete n	deletes message number n

When a message is deleted, it is placed in the WASTEBASKET folder. The WASTEBASKET is emptied with the Exit command (which also takes you out of the mail facility) and the PUrge command. While a message is in the WASTEBASKET folder it can be recovered using the SELect and Move commands.

FOLDERS

The standard mail folders are:

MAIL	holds mail messages
NEWMAIL	holds new mail messages
WASTEBASKET	holds deleted mail messages until you empty it with Exit or PUrge

You can also make your own folders for keeping important or related messages (using SELect and Move).

DIrectory/FOlder gives a listing of mail folders.

SELECTING FOLDERS

To go to another folder use SELect folder (e.g. SEL WASTEBASKET). SEL with no folder is the same as SEL MAIL. The currently selected folder is displayed in the top right corner of the screen.

MOVING FILES FROM FOLDER TO FOLDER

REAd the message you want to move, then Move "folder"

e.g. To recover a deleted message and move it to the MAIL folder

SELect WASTEBASKET

REAd the message

Move MAIL

Move/All "folder" moves all files in the current folder to the specified folder.

LEAVING THE MAIL FACILITY

Exit leaves mail and empties the WASTEBASKET folder.

Quit leaves mail without emptying the WASTEBASKET folder.

GENERAL

Ctrl-C (Cancel) returns you to the MAIL> prompt from within a mail command.

For more detailed help, you can enter Help at the MAIL> prompt.

2.5.11 EXIT Command

The EXIT command allows the user to leave the interactive WATSUN program, and has the form:

EXit

e.g. EXIT takes the user out of WATSUN. To restart WATSUN, type **WATSUN and press the RETURN key.**

2.6 Subcommands

The subcommand level allows the user to create new input data files or modify existing ones. It is invoked by issuing an EDIT command at the main command level (Select?). In the subcommand level, the user is prompted by the word "Command?". In response, the user is allowed to enter any number of subcommands in one line.

2.6.1 Modifying Specific Data Block Items

To modify a specific data block item, the user must first identify the data block he wishes to change by typing its unique one letter designation. For example, if the item he wishes to change is stored in the regulator data block, he would type the letter "R". Then, any further commands he issues will be carried out on the collector data block until he specifies another data block.

Each data block consists of several items which are numbered sequentially. To modify a specific item, the user simply types the item number followed by a space (or a comma) and the new item value.

Examples:

1) R

   - This command sets the regulator data block as the current block and lists the entire data block.

2) R 2 50 S

- This command sequence changes regulator item number 2 to a value of 50. Then it sets the simulation data block as the current one and lists the entire data block.

3) S 10 25 4 80 C 4 14.1

- The above sequence of commands will change the value of item number 10 in the simulation data block to 25. Then it will change the value of simulation item number 4 to 80. Finally, it will change the value of regulator item number 4 to 14.1. No data blocks will be displayed.

2.6.2 Modifying Profiles

Several WATSUN data blocks contain items which require profiles (ie. they consist of more than one value). These items are clearly identified by the word "PROFILE:" before the item description. To modify a profile, the user simply types the identifying block name and item number (or just the item number, if the current block is already correct). The program always prints out a full display of the profile values, and then prompts the user with the word "Profile?". A list of commands at this level can be obtained by pressing RETURN in response to this prompt, and more detailed information can be obtained by typing HELP. See Section 2.7 for information on the "Profile?" level commands.

There is no specific command for leaving the "Profile?" level and returning to the "Command?" level. Most of the commands that are intended for the "Command?" level will automatically move the program to that level. Similarly, "Select?" level commands will move the program to that level. Probably the

most convenient way to move to "Command?" level is to type a single letter block name. This will simply list the contents of a data block. However, if the user knows what he wishes to do next, such as change an item in a different data block, he may issue the commands for that. For example, if the user is currently in the profile for "Load" block item 12, and he types:

1 3 11.7

he will move out of the "Profile?" mode, the current block will remain "Load" and the value of the third item of that block will change to 11.7. He will then be prompted by "Command?".

2.6.3 LIST Subcommand

The LIST command displays the contents of all the data blocks required for the current solar system. The command has the form:

LIST

The data blocks are displayed on the user's terminal. As the display is rather long, this command should not be used if the user's time is limited.

2.6.4 TITL Subcommand

The TITL command allows the user to specify or modify a title line which is used to identify WATSUN simulation results. The form of the command is:

TITL

The user will then be asked to enter a title line.

NOTE: A title is not mandatory for running WATSUN simulations. Also the title should not be confused with the file name.

2.6.5 HELP Subcommand

The HELP command displays a list and description of all available subcommands along with the data blocks required for the current system module. The command has the form:

HELP

2.6.6 SAVE Subcommand

The SAVE command saves all modifications made to the current data file and then returns control to the main command level (Select?). The command has the form

SAVE

To permanently save the modifications, the user must use the SAVE command at the main command level.

2.6.7 QUIT Subcommand

The QUIT command returns to the main command level (Select?) without saving any changes. The command has the form:

QUIT

This command is used to abort the editing session. The program will ask the user if he wishes to save the changes he has made, to ensure that he does not discard them by mistake.

2.7 Profile Level Command Descriptions

The profile command level is designed to allow the user to modify those data items which require a profile (eg. Load item number 12 is a profile with 24 values representing the essential load distribution for a day). It is invoked by typing L12 from the subcommand level (Command?). At the Profile level the user is prompted by the word "Profile?". In response the user may enter any number of Profile level commands in one line.

2.7.1 Modifying Specific Profile Values

A profile consists of several values which are numbered sequentially. Once a current profile is chosen, the user may modify any one of the profile values by typing its identifying code number, followed by a space (or a comma) and the new profile value.

Example: 4 20.14 10 7 2 53.97

The above command sequence will change value numbers 4, 10, and 2 of the current profile to the specified new values (20.14, 7, and 53.97 respectively)

2.7.2 REPL Profile Command

The REPL command replaces all values in the current profile with the specified list of new values. The command has the form:

REPL < v1 < v2 < v3 < ... < vn > > > > >

where "vi" is the new ith value in the current profile,

"n" is the new number of values in the current profile.

If the list of new values is omitted, the user will be prompted for "n" new values. If more than "n" values are entered, the extra input will be ignored. If less than "n" values are entered, the user will be prompted for the remaining values.

The REPL command is useful if a new profile is to be entered, because it is not necessary to type a code number before every new value.

NOTE: The new values must be entered in order, starting with the first value.

2.7.3 DISP Profile Command

The DISP command displays the contents of the current profile. The command has the form:

DISP

2.7.4 HELP Profile Command

The HELP command displays a brief description of all available Profile commands. The command has the form:

HELP

A shorter HELP display may be obtained by simply pressing the RETURN key when prompted by "Profile?".

3 Input Data Description

As outlined in Chapter 2, Program structure and Command Descriptions, the parameters that describe the photovoltaic system to be simulated are contained in DATA files. These DATA fields are divided into data blocks; each data block contains parameters for a specific component of the system. The number of data blocks required depends on the system simulated. The table below lists the data blocks required for each system.

Block # / Name	1 S	2 R	3 A	4 D	5 B	6 C	7 G	8 D	9 L	10 E
SABB	X	X								X
ARRA			X	X						
BATT					X	X	X	X		
LOAD									X	

KEY to the single letter block names:

1. S - General Simulation data
2. R - Regulator data
3. A - Array data
4. D - Detailed Array data
5. B - General Battery data
6. C - Battery Charging Data
7. G - Battery Gasing Data
8. D - Battery Discharging Data
9. L - Load data
10. E - Economic Data

The following sections will list each data block in turn and provide a detailed description of all input parameters contained therein.

3.1 Simulation Data Block

The simulation data block is used to specify the simulation period, weather data, operational options and output options.

Simulation Data

1	Simulation Year (0 for TMY).....	0.00000	year
2	Simulation Period.....	365.000	days
3	Start Day Number (Jan 1=1, Feb 1 = 32, etc.)..	1.00000	day
4	Initial State of Charge.....	100.000	%
5	Detailed Print Interval (No=0, 1=hour,etc)....	0.00000	hr
6	Starting Hour of Detailed Print (No=0, 1-24)..	0.00000	hr
7	Detailed Analysis Period - Start Day.....	0.00000	day
8	- End Day.....	0.00000	day
9	Battery Temp Control (1=Fixed,2=Amb.,3=Min.)..	1.00000	
10	Constant Battery Temperature.....	20.0000	C
11	Initial Battery Temperature.....	20.0000	C
12	Relative Error Index (0 to 10).....	3.00000	
13	Maximum number of iterations.....	10.0000	
14	Economic Analysis Required (No=0, Yes=1).....	1.00000	

Parameter Descriptions

1. This parameter specifies the year for the weather data. WATSUN-PV uses Typical Meteorological Year (TMY) for all systems. To use the TMY weather data, the value of this parameter must be "0".
2. This parameter specifies the number of days for which the simulation is to be performed.
3. This parameter specifies the starting day number for the simulation. To calculate the start day, use the table below by adding the day of the month to the number corresponding to the that month.

Month	Number
January	0
February	31
March	59
April	90
May	120
June	151
July	181
August	212
September	243
October	273
November	304
December	334

4. This parameter specifies the initial condition of the battery, in terms of its state of charge.

5. This parameter specifies the detailed analysis period as follows:

   0 - no detailed analysis

   1 - detailed analysis every hour

   n - detailed analysis every n^{th} hour

   EXAMPLE: n=6 prints the detailed analysis every 6 hours.

6. This parameter specifies the hour in which the detailed print, as specified in 5.), begins to print.

7,8. These parameters specify the days of the simulation that the detailed print will occur for.

9. This parameter specifies the type of temperature control for the battery environment. There are three types of control:

   1 - Fixed temperature. The batteries are in a thermostatically controlled environment at a constant temperature.

   2 - Ambient temperature. The batteries are outside or in an unheated building, so that their temperature is the ambient temperature from the weather file.

   3 - Minimum temperature. The batteries are maintained above a certain minimum temperature. If the ambient temperature is high, they will warm up, but if it is low, they will not be permitted to cool below the minimum temperature.

   NOTE: If the batteries are operating under monitored temperature conditions, and this temperature is provided as a sixth hourly parameter in the weather file, (see Chapter 7), the battery temperature in the weather file will override the temperature specified in parameter 10. Thus, if parameter 9 is set to 1, the monitored battery temperature from the weather file would be used. If parameter 9 is set to 2, the ambient temperature from the weather file would be used. If parameter 9 is set to 3, the higher of the two would be used.

10. This parameter specifies the maintained battery temperature. If parameter 9 is set to 1, it is the constant temperature for the batteries. If parameter 9 is set to 2, this parameter is not used. If parameter 9 is set to 3, parameter 10 is the minimum permitted temperature for the batteries.

11. This parameter specifies the temperature at which the initial state of charge calculations for the battery are to be carried out.

12. This parameter specifies the precision of the iteration routine that solves for battery current and voltage. 0 is the lowest precision and 10 is the highest. Increasing the precision will increase program runtime.
13. This parameter specifies the maximum number of iterations permitted in the routine that solves for battery current and voltage. Decreasing this number will reduce precision and runtime.
14. This parameter indicates whether an economic analysis should be performed.

    0 - economic analysis will not be performed

    1 - economic analysis will be performed

3.2 Regulator Data Block

Control Data

1	Array Control (1=MPPT, 2=Clamped, 3=None).....	1.00000	
2	MPPT efficiency.....	95.0000	%
3	Reference Temp. for Maximum Charging Voltage..	20.0000	C
4	Maximum Charging Voltage at Ref. Temp.....	14.3000	V
5	Voltage Temperature Coefficient.....	0.50000E-02	V/deg C
6	Trickle Charge Control (1=no, 2=yes).....	1.00000	
7	Parameter not used.....	0.00000	
8	Regulator Type (1=Series, 2=Shunt).....	1.00000	
9	Regulator Relay Current.....	0.15000	Amps

Parameter Descriptions

1. This parameter specifies the type of array control provided in the system. There are three types:

   1. MPPT - Maximum Power Point Tracker. This controller varies the voltage and current from the array so that the maximum power (for the radiation input) is drawn off at all times. An efficiency must be specified. (see parameter 2)

   2. Clamped - Clamped Voltage Controller. This controller fixes the array voltage to the battery voltage for each hour, and determines array current output based on this voltage.

   3. None - No controller is provided for the array. Array voltage will be determined by battery voltage, as in the Clamped Voltage Controller. However, there is no regulator and hence no regulator current losses.

2. This parameter specifies the efficiency of the maximum power point tracker. It is not used for clamped voltage controllers or no-controller systems.

3. This parameter specifies the reference temperature at which the maximum charging voltage is specified. It is not used when there is no controller (parameter 1 set to 3).

4. This parameter specifies the maximum charging voltage for the batteries. Above this voltage, the strategy for battery protection will begin to operate (see parameter 6). This parameter is not used when there is no controller (parameter 1 set to 3).

5. This parameter specifies the rate at which maximum charging voltage changes with temperature. A positive number indicates that the maximum charging voltage will rise with decreasing temperature. This parameter is not used when there is no controller (parameter 1 set to 3).

6. This parameter specifies the technique used to protect the batteries from overcharging. If trickle charge is selected, the batteries will continue to be charged at the rate specified by parameter 4, once the maximum voltage has been reached. If no trickle charging is selected, the battery will be charged at a rate that holds it at the specified maximum voltage. Note that if parameter 1 is set to 3 (no array controller) there is no protection of the batteries against overcharging, so this parameter will be ignored by the program.

7. This parameter specifies the total time required to charge the batteries at the trickle current. If the size or number of batteries is changed, the trickle charge rate will then be adjusted accordingly. The total trickle charge time can be calculated by dividing the total nominal battery capacity by the trickle current. This parameter is not used if there is no trickle charger or no array controller.

8. This parameter specifies the type of regulator used, for purposes of determining the regulator losses in the system. Two types of regulators are permitted.

   1. Series Regulator - This regulator consists of a switch, either electronic or mechanical, in series with the array. It controls current to the battery by switching the array on or off. The switch draws a small current when the array is on, so the current loss to the system must be specified in parameter 9.

   2. Shunt Regulator - This regulator consists of a switch to shunt the current back to the array in order to control current to the battery. Since this switch is normally open, there is no current loss when the array is on. However, there is a diode in series with the array, to avoid short circuiting the battery when the shunt is operating. This diode causes a small voltage drop in the system, which must be specified in parameter 9.

   NOTE: If parameter 1 is set to 3 (no array controller) there is no regulator, so this parameter will be ignored by the program.

9. This parameter specifies the regulator relay (or transistor) current losses in the case of a series regulator, or the diode voltage drop in the case of a shunt regulator. See the descriptions under parameter 8 for further explanation.

   NOTE: If parameter 1 is set to 3 (no array controller) there is no regulator, so this parameter will be ignored by the program.

3.3 Array Data Block

Array Data

1	Number of Series Groups in Parallel.....	1.00000	
2	Number of Modules in Series.....	1.00000	
3	Area per Module.....	0.50000	m2
4	Tracking Method (1=no,2 axis,3=1 axis,4=azmt).	1.00000	
5	Collector Slope.....	60.0000	deg.
6	Collector Azimuth (0=to equator,+=west).....	0.00000	deg.
7	Reference Array Operating Temperature.....	20.0000	C
8	Reference Insolation Level.....	1000.00	W/m2
9	Reference MPP Voltage.....	16.0000	V
10	Reference MPP Current.....	4.50000	Amps
11	Reference Open Circuit Voltage.....	19.0000	V
12	Reference Short Circuit Current.....	4.80000	Amps
13	Array Lead-in resistance.....	0.00000	Ohms

Parameter Descriptions

1. This parameter specifies the number of series groups of modules that are connected in parallel to form one array. A series group may be a single module, or a number of modules in series.
2. This parameter specifies the number of modules connected in series to form each series group.
3. This parameter specifies the area of each module.
4. This parameter indicates the type of tracking method for the collectors. Four methods are permitted:

   1. No tracking. The collectors are fixed in one orientation. Slope and azimuth must be specified in parameters 4 and 5.

   2. Double axis tracking. The collectors track the sun perfectly. Parameters 4 and 5 are not used.

   3. Single axis tracking. The collectors are mounted on an axis that runs through the plane of the collector, and they track the sun by rotating about this axis. The slope and azimuth of this axis are specified

in parameters 4 and 5.

4. Azimuth tracking. The collectors are mounted on a fixed slope, and track the sun by changing their azimuth. The slope is specified in parameter 4, and parameter 5 is not used.

5. This parameter specifies the slope of the collector in the case of fixed or azimuth-tracking collectors. In the case of single and axis tracking, it specifies the slope of the tracking axis. The slope is measured from the horizontal to the back of the array (or to the tracking axis), and is always positive. This parameter is not used in the case of double axis tracking.

6. This parameter specifies the azimuth angle of the collector in the case of fixed collectors, or the azimuth angle of the tracking axis in the case of single axis tracking. Azimuth angle is measured with respect to a line pointing towards the equator, and is positive towards the west. Thus, for example, an array situated at 20° south latitude, oriented to point 15° west of due north, would have an azimuth angle of 15°. This parameter is not used for double axis tracking or azimuth tracking.

7. This parameter specifies the reference temperature at which module efficiency tests were performed.

8. This parameter specifies the reference insolation level at which module efficiency tests were performed.

9. This parameter specifies the voltage at the maximum power point for the module, under the reference conditions.

10. This parameter specifies the current at the maximum power point for the module, under the reference conditions.

11. This parameter specifies the open circuit voltage for the module, under the reference conditions.

12. This parameter specifies the short circuit current for the module, under the reference conditions.
13. This parameter specifies the resistence of the lead-in wires on the array side of the system.

3.4 Detailed Array Data Block

```
Detailed Array Data
-------------------
   1  Alpha..................................... 0.25000E-02 1/C
   2  Beta...................................... 0.50000
   3  Gamma..................................... 0.29000E-02 1/C
   4  Front Panel.....Solar Absorptance..... 0.10000
   5              .....Emissivity..... 0.95000
   6              .....Transmittance (visible)..... 0.95000
   7              .....Transmittance (infrared)..... 0.90000
   8  Back Panel......Emissivity..... 0.90000
   9  PROFILE:  Incidence Angle Modifiers (Vert.)...
        Angle Values.............................. degrees
      0.000     30.000     45.000     60.000     90.000
        Akt Values................................ unitless
      1.000      1.000      0.970      0.877      0.000
```

Parameter Descriptions

1. This parameter, alpha, is the temperature coefficient for module short circuit current. If alpha is positive, the short circuit current will rise linearly with increasing temperature.
2. This parameter, beta, is the radiation coefficient for module open circuit voltage. If beta is positive, open circuit voltage will rise slightly with increasing levels of radiation, based on a logarithmic equation provided in Chapter 6.
3. This parameter, gamma, is the temperature coefficient for module open circuit voltage. If gamma is positive, open circuit voltage will decrease linearly with increasing temperature.
4. This parameter specifies the solar absorptance of the front panel covering the solar cell.
5. This parameter specifies the emissivity of the front panel.

6. This parameter specifies the transmittance of the front panel in the range of visible wavelengths.
7. This parameter specifies the transmittance of the front panel in the range of infra-red wavelengths.
8. This parameter specifies the emissivity of the back panel of the module.
9. This profile specifies the angle of incidence and its associated incidence angle modifier for up to 5 incidence angles. As the incident angle of incoming radiation becomes more oblique (diverges from the normal) less radiation is transmitted through the front cover and more is reflected. The calculation procedure, dependent on the number of data pairs specified, is as follows:

Number of Points	Procedure
0	A_{RT} = 1.0 for all angle values
1	A_{RT} = constant for all angle values
2 to 5	A_{RT} = curve fit is performed using a cubic spline and the resulting curve is used to calculate A_{RT} for each hour

3.5 Battery Data Block

Battery Data

1	Battery Type (0=Lead-Acid, 1=NiCd).....	0.00000	
2	Battery Capacity.....	85.0000	amp-hrs
3	Nominal Battery Voltage.....	12.0000	V
4	Discharge Cut-off Voltage.....	10.5000	V
5	Number of Cells per Battery.....	6.00000	

Parameter Descriptions

1. This parameter indicates the type of battery being used

   0 - Lead-acid batteries

   1 - Nickel-cadmium batteries

2. This parameter specifies the nominal capacity of each battery.

   NOTE: The program does a calculation of capacity from the base case discharge curve (usually the curve in profile D6), and compares it to the specified nominal capacity. If the difference is greater than 10%, a warning message will appear.

3. This parameter specifies the nominal battery voltage.

4. This parameter specifies the voltage at which battery discharge will be cut off.

5. This parameter specifies the number of cells per battery.

3.6 Charge Curve Data Block

```
Charge Curve Data
-----------------
   1  Number of Charge Curves Supplied..... 5.00000
   2  PROFILE:  Temp. and Current for Each Curve....
        Temperature Values for Each Curve..... Celsius
      20.000     20.000     20.000    -20.000    -40.000
        Current Values for Each Curve..... Amps
       3.600      1.060      0.100      1.060      1.060
   4  PROFILE:  Cell Voltage vs. Time for Curve 1...
        Time..................................... hours
       0.000     18.000     19.000     20.000     22.000
        Voltage.................................. V
       2.030      2.200      2.250      2.300      2.550
   6  PROFILE:  Cell Voltage vs. Time for Curve 2...
        Time..................................... hours
       0.000     72.000     76.000     80.000     84.000
        Voltage.................................. V
       2.010      2.170      2.230      2.300      2.400
   8  PROFILE:  Cell Voltage vs. Time for Curve 3...
        Time..................................... hours
       0.000    980.000    983.000    986.000    990.000
        Voltage.................................. V
       2.000      2.250      2.251      2.252      2.254
  10  PROFILE:  Cell Voltage vs. Time for Curve 4...
        Time..................................... hours
       0.000     72.000     76.000     80.000     84.000
        Voltage.................................. V
       2.010      2.400      2.460      2.530      2.630
  12  PROFILE:  Cell Voltage vs. Time for Curve 5...
        Time..................................... hours
       0.000     72.000     76.000     80.000     84.000
        Voltage.................................. V
       2.010      2.500      2.560      2.630      2.730
```

Parameter Description

1. **This parameter indicates the number of charge curves supplied.**

2. This profile indicates the temperature and current for each charge curve supplied. The first pair apply to charge curve C4, the second pair to curve C6, and so on. Preferably 5 curves should be supplied. If this is the case, curve C6 is the base case. Curves C4 and C8 should be at the same temperature as C6, with C4 at a higher current and C8 at a lower current. Curves C10 and C12 should have the same current as the base case, but lower temperatures. If fewer than 5 charge curves are supplied, the following system should be observed for ordering them:

   1. Curves at the base temperature and varying currents appear before curves at base current and lower temperatures.

   2. No more than 3 curves at the base temperature should be supplied, and they should be in order of decreasing current.

   3. No more than 2 curves at lower temperatures and base current should be supplied, and they should be in order of decreasing temperature.

4,6, 8,10, 12 These profiles each provide 5 points on a charge curve for the battery. Each point consists of the average voltage per cell versus the time since the beginning of charging. The first point should be in the linear section of the curve. The second point should be the point where the curve bends i.e. becomes nonlinear. The remaining three points should be fairly evenly spaced along the nonlinear section of the curve.

3.7 Gasing Data Block

```
Gasing Data
-----------
   1  20-Hour Charge Current..................... 3.60000      Amps
   2  PROFILE:  Gasing Current vs (V - Vg).....
        Voltage Differential Above Initial Gasing.. V
       0.000      0.200      0.300      0.400      0.500
        Gasing Current wrt. 20-Hour Charge Rate.... I-20
       0.000      0.139      0.278      1.250      2.417
```

Parameter Description

1. This parameter specifies the 20-hour charge rate for the battery.

2. This profile provides 5 points on the curve of gasing current versus the voltage above the gasing point. Gasing current is specified as a multiple of the 20-hour charge rate specified in parameter 1. Voltage above gasing point is the cell voltage minus the voltage at which gasing begins.

3.8 Discharge Curve Data Block

```
Discharge Curve Data
--------------------
   1  Number of Discharge Curves Supplied..... 5.00000
   2  PROFILE:  Temp. and Current for Each Curve....
        Temperature Values for Each Curve..... Celsius
      20.000    20.000    20.000   -20.000   -40.000
        Current Values for Each Curve..... Amps
       3.600     1.060     0.100     1.060     1.060
   4  PROFILE:  Cell Voltage vs. Time for Curve 1...
        Time..................................... hours
       0.000    11.800    15.600    18.200    20.000
        Voltage.................................. V
       2.100     2.020     1.975     1.920     1.751
   6  PROFILE:  Cell Voltage vs. Time for Curve 2...
        Time..................................... hours
       0.000    47.200    62.400    72.800    80.000
        Voltage.................................. V
       2.100     2.020     1.975     1.920     1.751
   8  PROFILE:  Cell Voltage vs. Time for Curve 3...
        Time..................................... hours
       0.000   566.400   748.800   873.600   960.000
        Voltage.................................. V
       2.100     2.020     1.980     1.920     1.800
  10  PROFILE:  Cell Voltage vs. Time for Curve 4...
        Time..................................... hours
       0.000    28.300    37.400    43.700    48.000
        Voltage.................................. V
       2.050     2.010     1.980     1.960     1.751
  12  PROFILE:  Cell Voltage vs. Time for Curve 5...
        Time..................................... hours
       0.000    18.800    24.900    29.100    32.000
        Voltage.................................. V
       2.030     2.000     1.975     1.940     1.751
```

Parameter Description

1. **This parameter indicates the number of discharge curves supplied.**

2. **This profile indicates the temperature and current for each discharge curve supplied. The first pair apply to discharge curve D4, the second pair to curve D6, and so on. Preferably 5 curves should be supplied. If this is the case, curve D6 is the base case. Curves D4 and D8 should be at the same temperature as D6, with D4 at a higher current and D8**

at a lower current. Curves D10 and D12 should have the same current as the base case, but lower temperatures.

If fewer than 5 discharge curves are supplied, the following system should be observed for ordering them:

1. Curves at the base temperature and varying currents appear before curves at base current and lower temperatures.

2. No more than 3 curves at the base temperature should be supplied, and they should be in order of decreasing current.

3. No more than 2 curves at lower temperatures and base current should be supplied, and they should be in order of decreasing temperature.

4,6, 8,10, 12 These profiles each provide 5 points on a discharge curve for the battery. Each point consists of the average voltage per cell versus the time since the beginning of discharging. The first point should be in the linear section of the curve. The second point should be the point where the curve bends, i.e. becomes nonlinear. The remaining three points should be fairly evenly spaced along the nonlinear section of the curve.

3.9 Load Data Block

Load Data

1	Load Voltage (nominal).....	12.0000	V
2	Type of Load (1=current, 2=power).....	2.00000	
3	Minimum Load Voltage (LVD function).....	11.7000	V
4	Battery-to-Load Lead Resistance.....	0.00000	Ohms
5	Essential Load Delivery? (1=yes, 0=no).....	1.00000	
6	Number of Days in "weekdays".....	7.00000	days
7	Number of Days in "week".....	7.00000	days
8	Maximum Essential Load for "weekdays".....	0.00000	AMPS (W)
9	Maximum Essential Load for "weekends".....	0.00000	AMPS (W)
10	Maximum Full Load for "weekdays".....	100.000	AMPS (W)
11	Maximum Full Load for "weekends".....	0.00000	AMPS (W)
12	PROFILE: Essential Load Fraction - "weekdays".		fraction
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
13	PROFILE: Essential Load Fraction - "weekend"..		fraction
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
14	PROFILE: Total Load Fraction - "weekdays".....		fraction
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
15	PROFILE: Total Load Fraction - "weekends".....		fraction
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
	1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00		
16	PROFILE: Monthly load scale factors.....		
	1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00		

Parameter Description

1. **This nominal load voltage is the "system voltage" at which the loads specified are designed to operate. This parameter is used to ensure that the load specified is compatible with the components specified in other data blocks.**

2. **This parameter determines whether the load values specified are in current or power, specified in amps or watts respectively.**

3. The minimum load voltage value is the lowest voltage that the battery will be allowed to drop to on discharge before load is disconnected. This feature may be used to simulate the low voltage disconnect feature of a regulator.

4. This parameter specifies the load side wiring resistance.

5. This parameter specifies whether the system should attempt to meet an essential load in the case that it fails to meet the full load specified for the hour. In this case an essential load must also be specified for the hour.

6. This parameter specifies the number of days in the "weekdays" portion of the "week". Any value from 0 to the number of days in the week (see item 7) is valid. The weekend load schedule will be used for the remaining days.

7. This parameter specifies the number of days in a week of simulation.

8,9. These parameters specify the value of the "maximum" essential load during the "weekdays" and "weekends" respectively. The essential load is a profile; these parameters specify the maximum value of this profile. The minimum is assumed to be zero.

10,11 These parameters specify the value of the "maximum" full load during the "weekdays" and "weekends" respectively. The full load is a profile; these parameters specify the maximum value of this profile. The minimum is assumed to be zero.

12,13 These profiles describe the hourly variation of the essential load for "weekdays" and "weekends". Each hourly value represents the fraction which when multiplied by the appropriate "maximum" value (items 8,9) yields the actual load for that hour in watts or amps.

14,15 These profiles describe the hourly variation of the essential total load for "weekdays" and "weekends". Each hourly value represents the fraction which when multiplied by the appropriate "maximum" value (items 8,9) yields the actual load for that hour in watts or amps.

16. This profile describes how the "maximum" values described above vary from month to month. A value of 1.00 in the 3rd position indicates that all maximum values specified must be multiplied by the factor 1.00 for the month of March.

3.10 Economic Data Block

Economic Data

1	System Life	20.0000	year
2	Term of Loan	20.0000	year
3	Interest Rate on Loan	0.10000	decimal
4	Rate of Return (Discount Rate)	0.10000	decimal
5	Cost of Collector per Array Module	80.0000	$
6	Cost of Storage per Battery	50.0000	$
7	Cost of Auxiliary Energy	70.0000	$/MWh
8	Salvage Value at the End of System Life	0.00000	$
9	Other Fixed Costs	1000.00	$
10	Yearly Maintenance Cost	50.0000	$/year
11	Pro-rate Energies over One Year (0=no,1=yes)	1.00000	
12	PROFILE: Yearly Fuel Escalation for Life	percent	

0.00 13.00 13.00 10.00 10.00 10.00 10.00 7.00 7.00 7.00
7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00

Parameter Description

1. This parameter specifies the number of years that the system will operate before replacement is necessary.
2. This parameter specifies the number of years required for loan repayment. The program assumes that a loan is negotiated for the capital cost of the solar system.
3. This parameter specifies the interest rate for the loan described in parameter 2.
4. This parameter specifies the discounted rate of return. This value represents the interest rate paid by an alternative investment. The savings made by the solar system are discounted by this rate in order to give a true value of the savings.
5. This parameter specifies the cost of a collector module in the array.
6. This parameter specifies the cost of a battery.

7. This parameter specifies the point of use cost for each MWh of auxiliary energy. The user is responsible for determining the appropriate efficiency for the fuel type.

8. This parameter specifies the value of the solar system at the end of the life of the system.

9. This parameter specifies all other fixed costs associated with the installation of the solar system. The costs of wiring, collector supports, regulators, and installation labour should be included in this value.

10. This parameter specifies the cost for yearly maintenance of the solar system.

11. This parameter indicates whether or not to pro-rate the energy values over a one-year period, if the simulation is not one year long. This will be done automatically if the simulation is over one year. However, if it is less, the user has a choice between pro-rating the values found for the simulation period to a one year time span, or assuming that the PV system will be shut down for the rest of the year.

    0 - Do not pro-rate energy values.

    1 - Pro-rate energy values.

12. This profile specifies the percentage that the energy cost will increase relative to the rest of the economy for each year of the life of the system. Twenty (20) values are required by the program but only the first n values will be used (n is the number of years for the system life specified in parameter 1).

4 Output Data Description

The output of the WATSUN-PV simulation program is described to provide the user with a comprehensive yet concise picture of the operation of the system during the period of simulation. A number of distinct sections makeup the output listing provided:

1. Title Page
2. Energy Analysis Summary
3. Simulation Out of Range Information
4. State-of-Charge Histograms
5. Loss-of-Load Data
6. Economic Analysis Summary
7. Echo of Input Data
8. Discharge and Charge Curve Summary
9. Detailed Output

Printed at the top of each page are the version and update number (i.e. WATSUN-PV 2.0), the date and time of the simulation run, and a description of the simulation as input by the user (with the "TITLE" command).

4.1 Title Page

The title page displays the version and update number, and the date of release (i.e. WATSUN-PV 2.0 and January 1989).

Also on the title page are listed the details of the "RUN" directive including the type and number of arrays and batteries, and the load specified for the simulation. An example is given below.

```
**************************************
*                                    *
*                                    *
*                                    *
*          WATSUN-PV 2.0             *
*                                    *
*                                    *
*                                    *
*      UNIVERSITY OF WATERLOO        *
*           DECEMBER 1989            *
*                                    *
*                                    *
*                                    *
**************************************


DEVELOPED BY:

    THE SYSTEMS DESIGN ENERGY GROUP
    DEPARTMENT OF SYSTEMS DESIGN ENGINEERING


SIMULATION DATA FILE NAME: SIMU
     ARRAY DATA FILE NAME: A
   BATTERY DATA FILE NAME: B
      LOAD DATA FILE NAME: L
         NUMBER OF ARRAYS:         3
      NUMBER OF BATTERIES:       100
            LOAD MULTIPLE:         1

WATSUN-PV DEMONSTRATION
```

4.2 Energy Analysis Summary

The energy analysis summary table contains monthly centres of information pertaining to the energy flows within the system simulated. This table is always printed on a monthly basis - in the event that a simulation is terminated within a month, values only represent performance up to that point in the month. In total there are eight (8) columns in this table. A brief description of these follows:

i) Incident Radiation (MWh) - this value represents the gross radiation incident upon the array surface, considering both the array orientation and area.

ii) Available Array Output (MWh) - the amount of electrical energy which is available for output from the array to the battery and load. This may not necessarily be useable.

iii) Battery Energy Input (MWh) - this is the amount of energy which is put into the batteries during charge cycles in the month.

iv) Battery Energy Output (MWh) - this is the amount of energy which is taken out of the batteries during discharge cycles in the month.

v) Total Wiring Losses (MWh) - this is the amount of energy lost in the system wiring during the months.

vi) Energy Wasted (MWh) - this is the amount of energy that is available from the array but is not used to charge the battery or meet the load (because the batteries were full and the load was met).

vii) Energy Delivered (MWh) - the total amount of energy actually delivered to the load.

viii) Total Fraction Delivered - this is the portion (a value between 0 and 1) of the Total Load specified that was actually delivered to the load.

The following is an example of the Energy Analysis Summary for the simulation performed in the tutorial example previously.

SABB TMY INUVIK, NWT. WATSUN-PV 2.0 1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION

****
* ENERGY ANALYSIS SUMMARY *
****

MONTH	INCIDENT RADIATION (MWh)	AVAILABLE ARRAY OUTPUT (MWh)	BATTERY ENERGY INPUT (MWh)	BATTERY ENERGY OUTPUT (MWh)	TOTAL WIRING LOSSES (MWh)	ENERGY WASTED (MWh)	ENERGY DELIVERED (MWh)	TOTAL FRACTION DELIVERED
JAN	0.038	0.005	0.002	0.011	0.000	0.002	0.012	1.000
FEB	0.095	0.012	0.007	0.010	0.000	0.003	0.011	1.000
MAR	0.217	0.029	0.017	0.009	0.000	0.010	0.012	1.000
APR	0.289	0.039	0.018	0.008	0.000	0.018	0.012	1.000
MAY	0.268	0.036	0.011	0.009	0.000	0.021	0.012	1.000
JUN	0.244	0.032	0.011	0.008	0.000	0.018	0.012	1.000
JUL	0.249	0.033	0.010	0.009	0.000	0.019	0.012	1.000
AUG	0.166	0.021	0.010	0.010	0.000	0.009	0.012	1.000
SEP	0.106	0.014	0.009	0.010	0.000	0.003	0.012	1.000
OCT	0.093	0.012	0.008	0.011	0.000	0.003	0.012	1.000
NOV	0.033	0.004	0.003	0.011	0.000	0.001	0.012	1.000
DEC	0.000	0.000	0.000	0.012	0.000	0.000	0.012	1.000
TOT	1.797	0.238	0.106	0.119	0.000	0.105	0.146	1.000

4.3 Simulation Out of Range Information

Charge and discharge curves provided by the user characterize the performance of the batteries at certain values of temperature and current. The program is designed to interpolate between these curves, and to some extent it will also extrapolate beyond the range. However, the extrapolation is more uncertain than the interpolation. Therefore, when a simulation contains hours in which either the battery temperature or the current is beyond the range of the curves specified by the user, a report will appear below the Energy Analysis Summary in the Output Listing. An example follows.

```
.NPUT CHARGE AND DISCHARGE INFORMATION FOR THE BATTERIES WAS PROVIDED
'OR THE FOLLOWING TEMPERATURE RANGE:    -40.0 < TEMP <    20.0
.ND THE FOLLOWING CURRENT RANGE:    -3.60 < CURRENT <    3.60

:EMPERATURE DISTRIBUTION:          HOURS      PERCENTAGE OF SIMULATION PERIOD
:EMPERATURE <  -40.0:                151          1.7 %
 -40.0 < TEMPERATURE <    20.0:    8396         95.8 %
  20.0 < TEMPERATURE:                213          2.4 %

:URRENT DISTRIBUTION:          HOURS      PERCENTAGE OF SIMULATION PERIOD
:URRENT <  -3.60:                    0          0.0 %
 -3.60 < CURRENT <    3.60:      8760        100.0 %
  3.60 < CURRENT:                    0          0.0 %
```

4.4 State-of-Charge Histograms

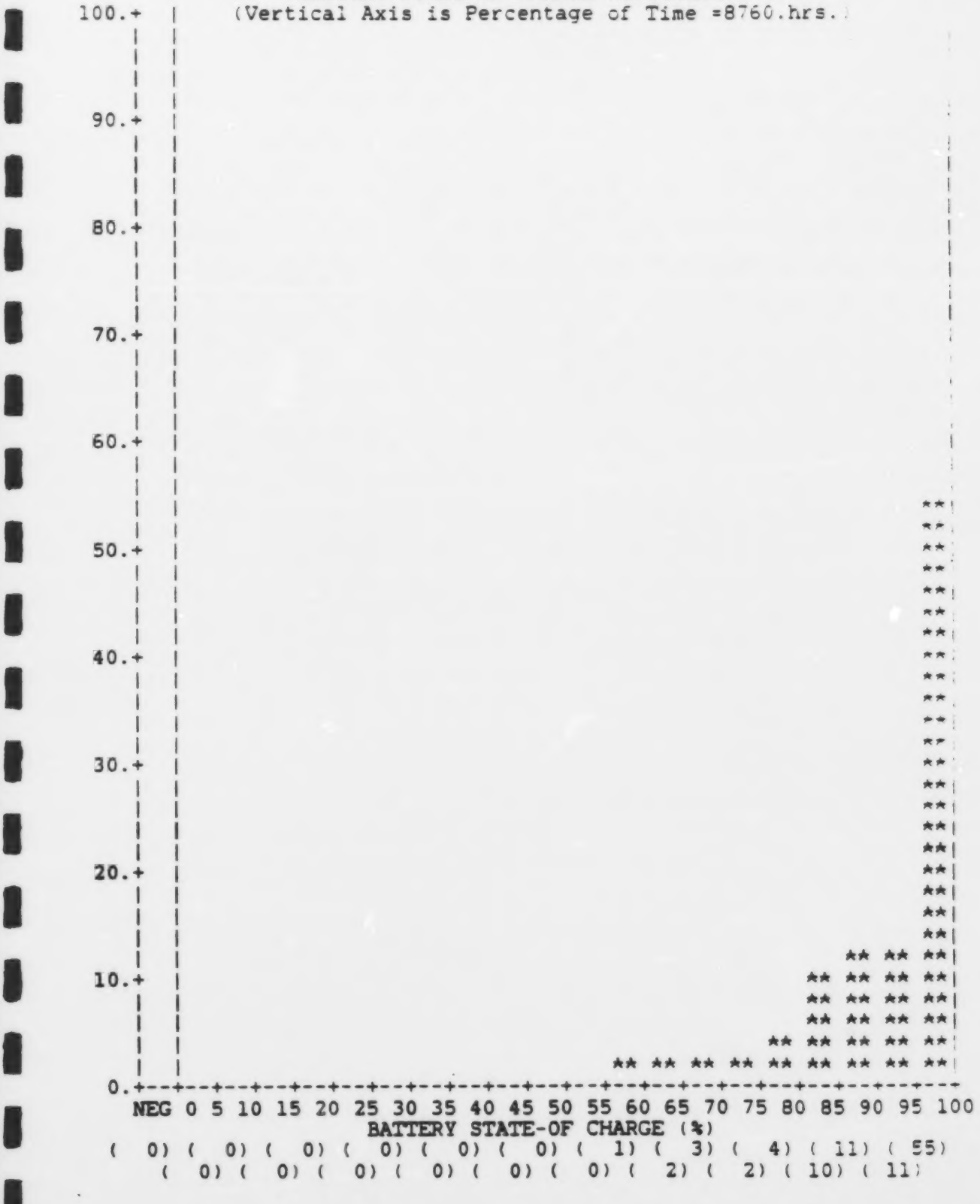
The State-of-Charge Histograms show the range of states-of-charge (SOC) that the battery experiences during the simulation. The Battery State-of-Charge Histogram, shows for a given SOC, the amount of time that the battery is in that state. This histogram takes into account all hours in the simulation.

The second histogram, the Charge Period-Initial State-of-Charge shows what the initial battery SOC was for hours when battery charging occurs.

It should be noted that the charging hours are always less than the total hours.

SABB TMY INUVIK, NWT. WATSUN-PV 2.0 1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION

BATTERY STATE-OF-CHARGE HISTOGRAM



```
3ABB  TMY  INUVIK, NWT.                WATSUN-PV 2.0  1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION
                CHARGE PERIOD INITIAL STATE-OF-CHARGE HISTOGRAM
     100.+  |    (Vertical Axis is Percentage of Time =3300.hrs.)
            |  |
            |  |
            |  |
            |  |
      90.+  |  |
            |  |
            |  |
            |  |
            |  |
      80.+  |  |
            |  |
            |  |                                                        **
            |  |                                                        **
      70.+  |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
      60.+  |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
      50.+  |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
      40.+  |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
      30.+  |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
      20.+  |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
            |  |                                                        **
      10.+  |  |                                                        **
            |  |                                           ** ** ** ** **
            |  |                                           ** ** ** ** **
            |  |                                           ** ** ** ** **
            |  |                                     ** ** ** ** ** ** **
       0.+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
          NEG 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
                                BATTERY STATE-OF CHARGE (%)
        (  0) (  0) (  0) (  0) (  0) (  0) (  0) (  0) (  2) (  7) ( 74)
           (  0) (  0) (  0) (  0) (  0) (  0) (  0) (  0) (  8) (  9)
```

4.5 Loss-of-Load Data

The first table shows all of the times the system could not meet the essential and/or the total load demands. The length of the consecutive hours of the down period are sorted in order of length and the frequency of occurrence in each of the essential and total load conditions is displayed. The total number of hours down is displayed at the bottom of each category and matches the table displayed in the Energy Analysis Summary.

The second table displays the number of hours a load was demanded in each of the categories and also provides a loss-of-load probability for each.

SABB TMY INUVIK, NWT. WATSUN-PV 2.0 1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION

TABLE OF CONSECUTIVE HOURS SYSTEM IS "DOWN"

PERIOD LENGTH [hrs]	FAILURE TO MEET LOAD [number of occurrences] ESSENTIAL	FULL
SYSTEM ABLE TO MEET LOAD REQUIREMENTS FOR ENTIRE SIMULATION PERIOD		
TOTAL	0	0

	TOTAL HOURS OF LOAD DEMAND THIS SIMULATION PERIOD ESSENTIAL	FULL
	0	1460
LOSS-OF-LOAD PROBABILITY	0.0000	0.0000

4.6 Economic Analysis Summary

If the economic analysis is requested by the user, (section 3.1 Simulation Data Block) the following listing will be included in the output.

```
ABB  TMY  INUVIK, NWT.                WATSUN-PV 2.0  1990 01 17 19:52:42
ATSUN-PV DEMONSTRATION

                              ***  ECONOMIC ANALYSIS  ***

     ** BASED ON A MINIMUM ANNUAL RATE OF RETURN OF 10.0%

     ** PRESENT WORTH (OPERATING ENERGY INCL.)($):       2665.68
                  (OPERATING ENERGY NOT INCL.)($):       2665.68

     ** ANNUAL WORTH (OPERATING ENERGY INCL.)($/YR):        313.11
                   (OPERATING ENERGY NOT INCL.)($/YR):        313.11

     ** LIFE-CYCLE UNIT COST (LUC), $/MWH:   912.904

     ** SOLAR LUC, $/MWH:   912.904

     ** BENEFIT/COST RATIO FOR SOLAR COMPONENT:      0.065

     ** SOLAR COMPONENT OF SYSTEM IS NOT COST-EFFECTIVE WITH A MARR OF 10.0%.

     ** SYSTEM COULD NOT PAY OFF WITH 0.0% MARR.
```

** NET SAVINGS OF SOLAR ENERGY SYSTEM **

YR	UNDISCOUNTED CASH FLOW	UNDISCOUNTED TOTAL	DISCOUNTED CASH FLOW	DISCOUNTED TOTAL
1	-302.89	-302.89	-275.35	-275.35
2	-301.56	-604.45	-249.22	-524.58
3	-300.06	-904.51	-225.44	-750.02
4	-298.75	-1203.26	-204.05	-954.07
5	-297.32	-1500.58	-184.61	-1138.68
6	-295.74	-1796.32	-166.94	-1305.62
7	-294.00	-2090.33	-150.87	-1456.49
8	-292.67	-2382.99	-136.53	-1593.02
9	-291.23	-2674.23	-123.51	-1716.53
10	-289.70	-2963.93	-111.69	-1828.23
11	-288.06	-3252.00	-100.96	-1929.19
12	-286.31	-3538.31	-91.23	-2020.42
13	-284.44	-3822.74	-82.39	-2102.81
14	-282.43	-4105.17	-74.37	-2177.18
15	-280.28	-4385.45	-67.10	-2244.28
16	-277.98	-4663.44	-60.50	-2304.78
17	-275.52	-4938.96	-54.51	-2359.29
18	-272.89	-5211.86	-49.08	-2408.37
19	-270.08	-5481.93	-44.16	-2452.53
20	-267.07	-5749.00	-39.70	-2492.23

The present worth is the total cost, using the current value of a dollar as a base, required to purchase and operate the solar system over the lifetime of the system. The first present worth value includes the cost of the energy required to operate the solar system while the second value ignores this cost. For a SABB system, these numbers will always be the same, but the capability has been included to provide for the addition of diesel hybrid simulations in WATSUN-PV 3.0.

The annual worth is the annual cost, using the current value of a dollar as a base, required to purchase and operate the solar system over the lifetime of the system. The first annual worth includes the cost of the energy required to operate the solar system while the second value ignores this cost. For a SABB system, these numbers will always be the same.

The life cycle unit cost, LUC, is the average cost per unit of energy delivered to the load over the lifetime of the system. The solar life cycle unit cost, SLUC, is the average cost per unit of solar energy delivered to the load over the lifetime of the system. These two numbers will always be the same for a SABB system.

The benefit/cost ratio for the solar component is the ratio of the value of energy saved by the solar component divided by the total cost of the solar component. This is based on the specified minimum annual rate of return and uses the current value of a dollar as a base. If the ratio is greater than 1, the solar component is cost effective at the specified MARR. If the ratio is less than 1, it is not cost effective.

The program then calculates the actual rate of return for the solar component, i.e. the MARR at which the benefit/cost ratio would be exactly 1. If the system could not pay off with MARR = 0%, the program will state that.

Finally, a table is provided to show the net savings of the solar energy system, year by year. One side shows the undiscounted cash flows per year and the resulting total. The second side shows the cash flow per year discounted according to the specified MARR, along with the resulting total. If the system pays off within its lifetime, the time to payout will be indicated in the table. This will occur at different times on the undiscounted and discounted sides of the table.

4.7 Echo of Input Data

All data blocks required by the system simulated are displayed in exactly the same order and format as in the interactive program. The following is a sample set of input data for the Stand Alone Battery Backup System.

SABB TMY INUVIK, NWT. WATSUN-PV 2.0 1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION

Simulation Data

1	Simulation Year (0 for TMY)	0.00000	year
2	Simulation Period	365.000	days
3	Start Day Number (Jan 1=1, Feb 1 = 32, etc.)	1.00000	day
4	Initial State of Charge	100.000	%
5	Detailed Print Interval (No=0, 1=hour,etc)	1.00000	hr
6	Starting Hour of Detailed Print (No=0, 1-24)	1.00000	hr
7	Detailed Analysis Period - Start Day	180.000	day
8	- End Day	181.000	day
9	Battery Temp Control (1=Fixed,2=Amb.,3=Min.)	2.00000	
10	Parameter not used	0.00000	
11	Initial Battery Temperature	20.0000	C
12	Relative Error Index (0 to 10)	3.00000	
13	Maximum number of iterations	10.0000	
14	Economic Analysis Required (No=0, Yes=1)	1.00000	

Control Data

1	Array Control (1=MPPT, 2=Clamped, 3=None)	1.00000	
2	MPPT efficiency	95.0000	%
3	Reference Temp. for Maximum Charging Voltage	20.0000	C
4	Maximum Charging Voltage at Ref. Temp	14.3000	V
5	Voltage Temperature Coefficient	0.50000E-02	V/deg C
6	Trickle Charge Control (1=no, 2=yes)	1.00000	
7	Parameter not used	0.00000	
8	Regulator Type (1=Series, 2=Shunt)	1.00000	
9	Regulator Relay Current	0.15000	Amps

Economic Data

1	System Life	20.0000	year
2	Term of Loan	20.0000	year
3	Interest Rate on Loan	0.10000	decimal
4	Rate of Return (Discount Rate)	0.10000	decimal
5	Cost of Collector per Array Module	80.0000	$
6	Cost of Storage per Battery	10.0000	$
7	Cost of Auxiliary Energy	70.0000	$/MWh
8	Salvage Value at the End of System Life	0.00000	$
9	Other Fixed Costs	1000.00	$
10	Yearly Maintenance Cost	50.0000	$/year
11	Pro-rate Energies over One Year (0=no,1=yes)	1.00000	
12	PROFILE: Yearly Fuel Escalation for Life	percent	

0.00 13.00 13.00 10.00 10.00 10.00 10.00 7.00 7.00 7.00
7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00

ARRA TMY INUVIK, NWT. WATSUN-PV 2.0 1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION

Array Data

1	Number of Series Groups in Parallel	1.00000	
2	Number of Modules in Series	1.00000	
3	Area per Module	0.50000	m2
4	Tracking Method (1=no,2 axis,3=1 axis,4=azmt.)	1.00000	
5	Collector Slope	75.0000	deg.
6	Collector Azimuth (0=to equator,+=west)	0.00000	deg.
7	Reference Array Operating Temperature	20.0000	C
8	Reference Insolation Level	1000.00	W/m2
9	Reference MPP Voltage	16.0000	V
10	Reference MPP Current	4.50000	Amps
11	Reference Open Circuit Voltage	19.0000	V
12	Reference Short Circuit Current	4.80000	Amps
13	Array Lead-in resistance	0.00000	Ohms

Detailed Array Data

1	Alpha	0.25000E-02	1/C
2	Beta	0.50000	
3	Gamma	0.29000E-02	1/C
4	Front Panel.....Solar Absorptance	0.10000	
5	.....Emissivity	0.95000	
6	.....Transmittance (visible)	0.95000	
7	.....Transmittance (infrared)	0.90000	
8	Back Panel.....Emissivity	0.90000	
9	PROFILE: Incidence Angle Modifiers (Vert.)...		

Angle Values..... degrees

0.000	30.000	45.000	60.000	90.000

Akt Values..... unitless

1.000	1.000	0.970	0.877	0.000

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Battery Data

1	Battery Type (0=Lead-Acid, 1=NiCd).....	0.00000	
2	Battery Capacity.....	85.0000	amp-hrs
3	Nominal Battery Voltage.....	12.0000	V
4	Discharge Cut-off Voltage.....	10.5000	V
5	Number of Cells per Battery.....	6.00000	

Charge Curve Data

1	Number of Charge Curves Supplied.....	5.00000			
2	PROFILE: Temp. and Current for Each Curve....				
	Temperature Values for Each Curve..... Celsius				
	20.000	20.000	20.000	-20.000	-40.000
	Current Values for Each Curve..... Amps				
	3.600	1.060	0.100	1.060	1.060
4	PROFILE: Cell Voltage vs. Time for Curve 1...				
	Time..... hours				
	0.000	18.000	19.000	20.000	22.000
	Voltage..... V				
	2.030	2.200	2.250	2.300	2.550
6	PROFILE: Cell Voltage vs. Time for Curve 2...				
	Time..... hours				
	0.000	72.000	76.000	80.000	84.000
	Voltage..... V				
	2.010	2.170	2.230	2.300	2.400
8	PROFILE: Cell Voltage vs. Time for Curve 3...				
	Time..... hours				
	0.000	980.000	983.000	986.000	990.000
	Voltage..... V				
	2.000	2.250	2.251	2.252	2.254
10	PROFILE: Cell Voltage vs. Time for Curve 4...				
	Time..... hours				
	0.000	72.000	76.000	80.000	84.000
	Voltage..... V				
	2.010	2.400	2.460	2.530	2.630
12	PROFILE: Cell Voltage vs. Time for Curve 5...				
	Time..... hours				
	0.000	72.000	76.000	80.000	84.000
	Voltage..... V				
	2.010	2.500	2.560	2.630	2.730

Gasing Data

1	20-Hour Charge Current.....	3.60000	Amps
2	PROFILE: Gasing Current vs (V - Vg).....		
	Voltage Differential Above Initial Gasing.. V		
	0.000	0.200	0.300	0.400	0.500
	Gasing Current wrt. 20-Hour Charge Rate.... I-20				
	0.000	0.139	0.278	1.250	2.417

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WATSUN-PV DEMONSTRATION

Discharge Curve Data

1	Number of Discharge Curves Supplied.....	5.00000			
2	PROFILE: Temp. and Current for Each Curve....				
	Temperature Values for Each Curve..... Celsius				
	20.000	20.000	20.000	-20.000	-40.000
	Current Values for Each Curve..... Amps				
	3.600	1.060	0.100	1.060	1.060
4	PROFILE: Cell Voltage vs. Time for Curve 1...				
	Time..... hours				
	0.000	11.800	15.600	18.200	20.000
	Voltage..... V				
	2.100	2.020	1.975	1.920	1.751
6	PROFILE: Cell Voltage vs. Time for Curve 2...				
	Time..... hours				
	0.000	47.200	62.400	72.800	80.000
	Voltage..... V				
	2.100	2.020	1.975	1.920	1.751
8	PROFILE: Cell Voltage vs. Time for Curve 3...				
	Time..... hours				
	0.000	566.400	748.800	873.600	960.000
	Voltage..... V				
	2.100	2.020	1.980	1.920	1.800
10	PROFILE: Cell Voltage vs. Time for Curve 4...				
	Time..... hours				
	0.000	28.300	37.400	43.700	48.000
	Voltage..... V				
	2.050	2.010	1.980	1.960	1.751
12	PROFILE: Cell Voltage vs. Time for Curve 5...				
	Time..... hours				
	0.000	18.800	24.900	29.100	32.000
	Voltage..... V				
	2.030	2.000	1.975	1.940	1.751

LOAD TMY INUVIK, NWT. WATSUN-PV 2.0 1990 01 17 19:51:41
WATSUN-PV DEMONSTRATION

Load Data

1	Load Voltage (nominal).....	12.0000	V
2	Type of Load (1=current, 2=power).....	2.00000	
3	Minimum Load Voltage (LVD function).....	11.7000	V
4	Battery-to-Load Lead Resistance.....	0.00000	Ohms
5	Essential Load Delivery? (1=yes, 0=no).....	0.00000	
6	Number of Days in "weekdays".....	7.00000	days
7	Number of Days in "week".....	7.00000	days
8	Maximum Essential Load for "weekdays".....	0.00000	AMPS (W)
9	Maximum Essential Load for "weekends".....	0.00000	AMPS (W)
10	Maximum Full Load for "weekdays".....	100.000	AMPS (W)
11	Maximum Full Load for "weekends".....	0.00000	AMPS (W)

12 PROFILE: Essential Load Fraction - "weekdays". fraction

0.30	0.30	0.30	0.30	0.30	0.30	0.60	0.90	0.60	0.60	0.45	0.45
0.45	0.45	0.45	0.45	0.60	0.90	0.90	0.90	0.60	0.30	0.30	0.30

13 PROFILE: Essential Load Fraction - "weekend".. fraction

0.30	0.30	0.30	0.30	0.30	0.30	0.60	0.90	0.60	0.60	0.45	0.45
0.45	0.45	0.45	0.45	0.60	0.90	0.90	0.90	0.60	0.30	0.30	0.30

14 PROFILE: Total Load Fraction - "weekdays"..... fraction

1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

15 PROFILE: Total Load Fraction - "weekends"..... fraction

0.30	0.30	0.30	0.30	0.30	0.30	0.60	0.90	0.60	0.60	0.45	0.45
0.45	0.45	0.45	0.45	0.60	0.90	0.90	0.90	0.60	0.30	0.30	0.30

16 PROFILE: Monthly load scale factors.....

1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

4.8 Discharge and Charge Curve Summary

The user input data provides discharge and charge information for the batteries as curves of voltage versus time. The program processes this information into curves of voltage versus state of charge (SOC) for use in the hour-by-hour simulation routines. An output of the results of this process is provided so that the user can verify that the battery will perform as expected. A sample of this output is provided.

SABB TMY INUVIK, NWT. WATSUN-PV 2.0 1990 01 17 19:50:42
WATSUN-PV DEMONSTRATION

DI..ARGE CURVE INPUT DATA, WITH SOC:
TIME [HOURS], VOLTAGE [VOLTS], AND SOC []

TEMP(1) = 20.0 C, CURRENT(1) = -3.60 AMPS, CAPACITY:					72.03 A-HR	
TIME:	0.00	11.80	15.60	18.20	20.00	20.01
VOLTAGE:	2.10	2.02	1.98	1.92	1.75	1.75
CHARGE:	1.0000	0.4102	0.2203	0.0903	0.0004	0.0000
TEMP(2) = 20.0 C, CURRENT(2) = -1.06 AMPS, CAPACITY:					84.83 A-HR	
TIME:	0.00	47.20	62.40	72.80	80.00	80.03
VOLTAGE:	2.10	2.02	1.98	1.92	1.75	1.75
CHARGE:	1.0000	0.4102	0.2203	0.0903	0.0004	0.0000
TEMP(3) = 20.0 C, CURRENT(3) = -0.10 AMPS, CAPACITY:					98.36 A-HR	
TIME:	0.00	566.40	748.80	873.60	960.00	983.57
VOLTAGE:	2.10	2.02	1.98	1.92	1.80	1.75
CHARGE:	1.0000	0.4241	0.2387	0.1118	0.0240	0.0000
TEMP(4) = -20.0 C, CURRENT(4) = -1.06 AMPS, CAPACITY:					50.89 A-HR	
TIME:	0.00	28.30	37.40	43.70	48.00	48.01
VOLTAGE:	2.05	2.01	1.98	1.96	1.75	1.75
CHARGE:	1.0000	0.4106	0.2210	0.0898	0.0003	0.0000
TEMP(5) = -40.0 C, CURRENT(5) = -1.06 AMPS, CAPACITY:					33.93 A-HR	
TIME:	0.00	18.80	24.90	29.10	32.00	32.01
VOLTAGE:	2.03	2.00	1.98	1.94	1.75	1.75
CHARGE:	1.0000	0.4127	0.2221	0.0909	0.0003	0.0000

CHARGE CURVE INPUT DATA, WITH SOC:
IE [HOURS], VOLTAGE [VOLTS], AND SOC []

TEMP(1) = 20.0 C, CURRENT(1) = 3.60 AMPS, CAPACITY:					72.03 A-HR	
TIME:	0.00	18.00	19.00	20.00	22.00	22.13
VOLTAGE:	2.03	2.20	2.25	2.30	2.55	2.58
CHARGE:	-0.0590	0.8407	0.8840	0.9215	0.9989	1.0000
TEMP(2) = 20.0 C, CURRENT(2) = 1.06 AMPS, CAPACITY:					84.83 A-HR	
TIME:	0.00	72.00	76.00	80.00	84.00	86.13
VOLTAGE:	2.01	2.17	2.23	2.30	2.40	2.47
CHARGE:	0.0361	0.9358	0.9615	0.9680	0.9883	1.0000
TEMP(3) = 20.0 C, CURRENT(3) = 0.10 AMPS, CAPACITY:					98.36 A-HR	
TIME:	0.00	980.00	983.00	986.00	990.00	990.55
VOLTAGE:	2.00	2.25	2.25	2.25	2.25	2.25
CHARGE:	-0.0024	0.9940	0.9966	0.9986	1.0000	1.0000
TEMP(4) = -20.0 C, CURRENT(4) = 1.06 AMPS, CAPACITY:					50.89 A-HR	
TIME:	0.00	72.00	76.00	80.00	84.00	86.13
VOLTAGE:	2.01	2.40	2.46	2.53	2.63	2.70
CHARGE:	-0.6066	0.8930	0.9358	0.9466	0.9804	1.0000
TEMP(5) = -40.0 C, CURRENT(5) = 1.06 AMPS, CAPACITY:					33.93 A-HR	
TIME:	0.00	72.00	76.00	80.00	84.00	86.13
VOLTAGE:	2.01	2.50	2.56	2.63	2.73	2.80
CHARGE:	-1.4098	0.8396	0.9038	0.9199	0.9706	1.0000

4.9 Detailed Output

The detailed output will be printed if requested by the user (see Section 3.1 Simulation Data Block for details). A sample output for SABB is shown on the following page.

```
SABB  TMY  INUVIK, NWT.                WATSUN-PV 2.0  1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION

EXPLANATION OF COLUMNS IN THE DETAILED ENERGY ANALYSIS SUMMARY
 DAY  DAY NUMBER
 HR   HOUR OF THE DAY
 TA   AMBIENT TEMPERATURE (C)
 WVEL WIND VELOCITY (M/S)
 HT   RADIATION/AREA OF COLLECTOR (WH/M2)
 PARR ENERGY PROVIDED BY THE ARRAY (WH)
 BATI ENERGY PUT INTO THE BATTERY (WH)
 BATO ENERGY TAKEN OUT OF THE BATTERY (WH)
 VB   BATTERY VOLTAGE (V)
 WIRL TOTAL WIRING LOSSES (WH)
 WAST TOTAL ENERGY WASTED (WH)
 DELD ENERGY DELIVERED TO THE LOAD (WH)
 FRAC FRACTION OF TOTAL LOAD MET
 LOAD TOTAL LOAD DEMAND (WH)
 ELOD ESSENTIAL LOAD DEMAND (WH)
```

SABB TMY INUVIK, NWT. WATSUN PV 2.0 1990 01 17 19:52:42
WATSUN-PV DEMONSTRATION
*** DAY : 180 *** COLLECTOR AREA : 1.50 M2 *** NUMBER OF BATTERIES : 100 ***

DAY	HR	TA (C)	WVEL (M/S)	HT (MH/M2)	PARR (MH)	BAT1 (MH)	BATO (MH)	VB (V)	WIRL (MH)	WAST (MH)	DELD (MH)	FRAC	LOAD (MH)	ELOD (MH)
180	1	20.0	3.9	9.56	1.65	0.000E+00	98.4	12.7	0.000E+00	0.826E-01	100.	1.00	100.	0.000E+00
180	2	18.0	3.9	17.8	3.08	2.92	0.000E+00	13.1	0.000E+00	0.154	0.000E+00	1.00	0.000E+00	0.000E+00
180	3	18.0	3.9	28.0	4.86	4.61	0.000E+00	13.1	0.000E+00	0.243	0.000E+00	1.00	0.000E+00	0.000E+00
180	4	16.0	3.9	36.0	6.26	5.95	0.000E+00	13.2	0.000E+00	0.313	0.000E+00	1.00	0.000E+00	0.000E+00
180	5	12.0	3.9	66.5	11.7	11.1	0.000E+00	13.3	0.000E+00	0.584	0.000E+00	1.00	0.000E+00	0.000E+00
180	6	12.0	3.9	61.1	10.7	10.2	0.000E+00	13.3	0.000E+00	0.536	0.000E+00	1.00	0.000E+00	0.000E+00
180	7	13.0	3.9	148.	26.5	0.000E+00	74.8	12.8	0.000E+00	1.33	100.	1.00	100.	0.000E+00
180	8	13.0	3.9	338.	63.7	60.5	0.000E+00	13.5	0.000E+00	3.18	0.000E+00	1.00	0.000E+00	0.000E+00
180	9	15.0	3.9	516.	101.	96.3	0.000E+00	13.6	0.000E+00	5.09	0.000E+00	1.00	0.000E+00	0.000E+00
180	10	16.0	3.9	682.	139.	0.000E+00	0.000E+00	13.7	0.000E+00	139.	0.000E+00	1.00	0.000E+00	0.000E+00
180	11	19.0	3.9	831.	174.	0.000E+00	0.000E+00	13.6	0.000E+00	174.	0.000E+00	1.00	0.000E+00	0.000E+00
180	12	22.0	3.9	920.	196.	-.129E-04	0.000E+00	13.5	0.000E+00	196.	0.000E+00	1.00	0.000E+00	0.000E+00
180	13	23.0	3.9	838.	175.	66.7	0.000E+00	13.4	0.000E+00	8.77	100.	1.00	100.	0.000E+00
180	14	25.0	3.9	676.	137.	0.000E+00	0.000E+00	13.3	0.000E+00	137.	0.000E+00	1.00	0.000E+00	0.000E+00
180	15	25.0	3.9	519.	102.	0.000E+00	0.000E+00	13.3	0.000E+00	102.	0.000E+00	1.00	0.000E+00	0.000E+00
180	16	25.0	3.9	385.	73.1	0.000E+00	0.000E+00	13.3	0.000E+00	73.1	0.000E+00	1.00	0.000E+00	0.000E+00
180	17	26.0	3.9	344.	64.6	0.000E+00	0.000E+00	13.3	0.000E+00	64.6	0.000E+00	1.00	0.000E+00	0.000E+00
180	18	26.0	3.9	155.	27.8	0.000E+00	0.000E+00	13.3	0.000E+00	27.8	0.000E+00	1.00	0.000E+00	0.000E+00
180	19	26.0	3.9	116.	20.6	0.000E+00	80.5	12.7	0.000E+00	1.09	100.	1.00	100.	0.000E+00
180	20	26.0	3.9	88.9	15.6	14.9	0.000E+00	13.0	0.000E+00	0.782	0.000E+00	1.00	0.000E+00	0.000E+00
180	21	26.0	3.9	64.7	11.3	10.7	0.000E+00	12.9	0.000E+00	0.565	0.000E+00	1.00	0.000E+00	0.000E+00
180	22	25.0	3.9	34.3	5.95	5.65	0.000E+00	13.0	0.000E+00	0.297	0.000E+00	1.00	0.000E+00	0.000E+00
180	23	24.0	3.9	23.4	4.05	3.85	0.000E+00	13.0	0.000E+00	0.203	0.000E+00	1.00	0.000E+00	0.000E+00
180	24	23.0	3.9	12.7	2.18	2.07	0.000E+00	13.0	0.000E+00	0.109	0.000E+00	1.00	0.000E+00	0.000E+00
180TOT		20.6	3.9	0.691E+04	0.138E+04	295.	254.	13.2	0.000E+00	936.	400.	1.00	400.	0.000E+00
181	1	21.0	3.9	11.2	1.93	0.000E+00	98.2	12.7	0.000E+00	0.963E-01	100.	1.00	100.	0.000E+00
181	2	19.0	3.9	19.8	3.43	3.26	0.000E+00	13.1	0.000E+00	0.171	0.000E+00	1.00	0.000E+00	0.000E+00
181	3	19.0	3.9	19.4	3.35	3.19	0.000E+00	13.1	0.000E+00	0.168	0.000E+00	1.00	0.000E+00	0.000E+00
181	4	20.0	3.9	33.9	5.88	5.59	0.000E+00	13.1	0.000E+00	0.294	0.000E+00	1.00	0.000E+00	0.000E+00
181	5	20.0	3.9	81.9	14.4	13.7	0.000E+00	13.1	0.000E+00	0.722	0.000E+00	1.00	0.000E+00	0.000E+00
181	6	19.0	3.9	108.	19.2	18.2	0.000E+00	13.1	0.000E+00	0.959	0.000E+00	1.00	0.000E+00	0.000E+00
181	7	18.0	3.9	135.	24.2	0.000E+00	77.0	12.8	0.000E+00	1.21	100.	1.00	100.	0.000E+00
181	8	19.0	3.9	327.	61.4	58.4	0.000E+00	13.3	0.000E+00	3.07	0.000E+00	1.00	0.000E+00	0.000E+00
181	9	21.0	3.9	443.	85.4	81.1	0.000E+00	13.3	0.000E+00	4.27	0.000E+00	1.00	0.000E+00	0.000E+00
181	10	21.0	3.9	695.	142.	134.	0.000E+00	13.5	0.000E+00	7.14	0.000E+00	1.00	0.000E+00	0.000E+00
181	11	22.0	3.9	813.	170.	0.000E+00	0.000E+00	13.4	0.000E+00	170.	0.000E+00	1.00	0.000E+00	0.000E+00
181	12	22.0	3.9	841.	176.	0.000E+00	0.000E+00	13.4	0.000E+00	176.	0.000E+00	1.00	0.000E+00	0.000E+00
181	13	23.0	3.9	807.	168.	0.000E+00	0.000E+00	13.4	0.000E+00	67.9	100.	1.00	100.	0.000E+00
181	14	24.0	3.9	802.	167.	0.000E+00	0.000E+00	13.4	0.000E+00	167.	0.000E+00	1.00	0.000E+00	0.000E+00
181	15	24.0	3.9	697.	142.	0.000E+00	0.000E+00	13.4	0.000E+00	142.	0.000E+00	1.00	0.000E+00	0.000E+00
181	16	25.0	3.9	548.	108.	-.636E-05	0.000E+00	13.3	0.000E+00	108.	0.000E+00	1.00	0.000E+00	0.000E+00
181	17	25.0	3.9	342.	64.3	0.000E+00	0.000E+00	13.4	0.000E+00	64.3	0.000E+00	1.00	0.000E+00	0.000E+00
181	18	24.0	3.9	149.	26.7	-.160E-05	0.000E+00	13.4	0.000E+00	26.7	0.000E+00	1.00	0.000E+00	0.000E+00
181	19	23.0	3.9	88.6	15.6	0.000E+00	85.3	12.7	0.000E+00	0.865	100.	1.00	100.	0.000E+00
181	20	24.0	3.9	79.0	13.9	13.2	0.000E+00	13.0	0.000E+00	0.694	0.000E+00	1.00	0.000E+00	0.000E+00
181	21	24.0	3.9	56.1	9.87	9.38	0.000E+00	13.0	0.000E+00	0.494	0.000E+00	1.00	0.000E+00	0.000E+00
181	22	24.0	3.9	41.0	7.13	6.77	0.000E+00	13.0	0.000E+00	0.357	0.000E+00	1.00	0.000E+00	0.000E+00
181	23	23.0	3.9	20.1	3.54	3.37	0.000E+00	13.0	0.000E+00	0.177	0.000E+00	1.00	0.000E+00	0.000E+00
181	24	21.0	3.9	7.61	1.31	1.25	0.000E+00	13.0	0.000E+00	0.656E-01	0.000E+00	1.00	0.000E+00	0.000E+00
181TOT		22.0	3.9	0.717E+04	0.143E+04	452.	260.	13.2	0.000E+00	942.	400.	1.00	400.	0.000E+00

5. System Model Descriptions

5.1 SABB - Stand Alone Battery Back-up

5.1.1 System Configuration

The Stand Alone Battery Back-up photovoltaic system has 3 major components - as depicted in Figure 5.1.1. The array, the battery, and the load are interconnected by the charge control regulator, and the load controller. As modelled in WATSUN-PV, the load controller may be excluded if desired. With the load controller, the system delivers to both full and essential loads, with priority given to the essential load. In the absence of the load controller only a full load is delivered - if possible. Wiring and line losses for the system are modelled as inefficiencies in the charge regulator.

5.1.2 Operating Strategy

The operating strategy of the SABB system defines the action of the system when subjected to a variety of operating conditions including; solar radiation, battery SOC (initial) and load imposed. Dependent on the nature of these conditions the system, in any given hour, may be observed to operate in one of six (6) modes; namely:

MODE 1. TOTAL LOAD MET, BATTERIES CHARGED
MODE 2. TOTAL LOAD MET, BATTERIES DISCHARGED
MODE 3. ESSENTIAL LOAD MET, BATTERIES CHARGED
(TOTAL LOAD NOT MET)
MODE 4. ESSENTIAL LOAD MET, BATTERIES DISCHARGED
(TOTAL LOAD NOT MET)
MODE 5. ESSENTIAL LOAD NOT MET, TOTAL LOAD NOT MET
MODE 6. TOTAL LOAD NOT MET, ESSENTIAL LOAD NOT PRESENT,

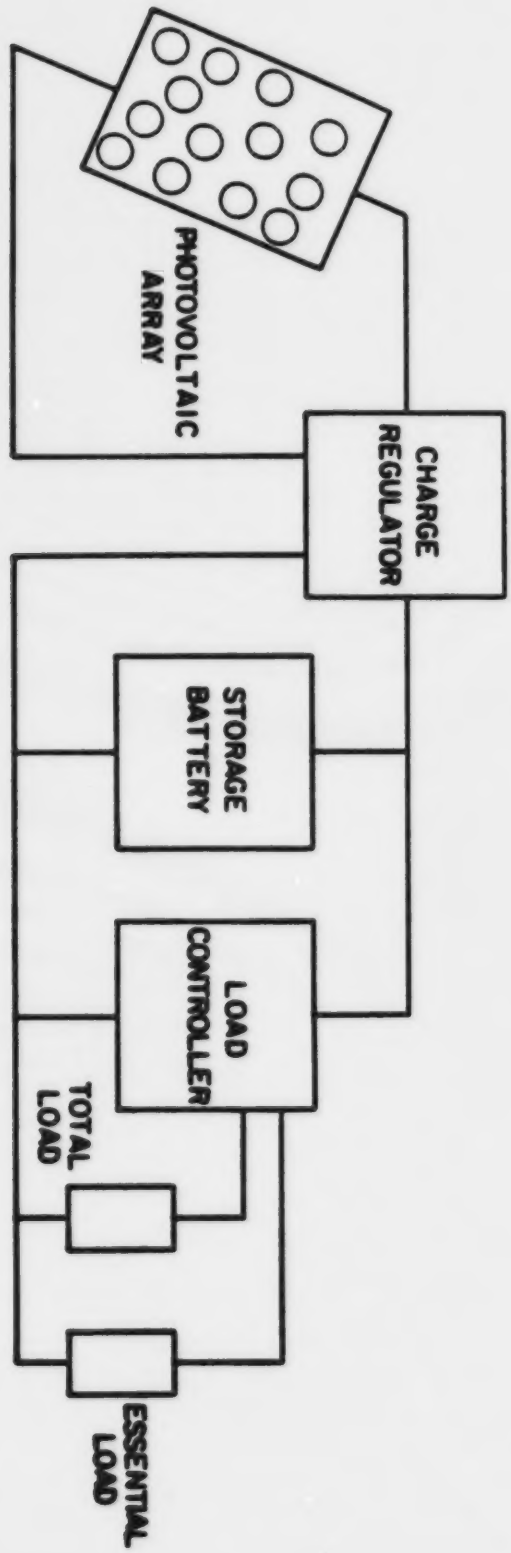

Figure 5.1-1 - SABB System Configuration

MODE 1. TOTAL LOAD MET - BATTERIES CHARGED

In this mode, the load specified can be met by the energy from the array in addition there may be excess energy available to charge the batteries. Included in this case would be the situation where the array energy exactly equalled the load energy required - the batteries would not be charged or discharged. If during charge the batteries reach a SOC = 1, then charging ceases, and the excess energy is wasted.

MODE 2. TOTAL LOAD MET - BATTERIES DISCHARGED

In this mode, the array energy was less than the required load energy. The batteries were discharged to supply the deficit. The battery SOC did not fall below the minimum SOC.

MODE 3. ESSENTIAL LOAD MET - BATTERIES CHARGED

In this mode, the total load energy requirement was greater than the energy available from the array and the energy remaining in the batteries. The energy available from the array was greater than the essential load, with the excess being used to charge the batteries. In this case, if the battery SOC became equal to one (1), the remainder of the energy would be wasted.

MODE 4. ESSENTIAL LOAD MET - BATTERIES DISCHARGED

In this mode, the essential load was met after the system failed to meet the total load, but battery energy was required to meet the essential load fully.

MODE 5. TOTAL LOAD NOT MET - ESSENTIAL LOAD NOT MET

In this mode, the available array energy plus the battery energy was insufficient to meet either load. Any array energy was used to charge the batteries, otherwise the battery SOC does not change.

MODE 6. TOTAL LOAD NOT MET - NO ESSENTIAL LOAD

In this mode, there was insufficient energy from the array and batteries to meet the total load. The essential load option was not in use, thus no load was delivered. Any available array energy was used to charge the batteries, otherwise the battery SOC does not change.

ADDENDUM TO CHAPTER 5

In WATSUN-PV 2.0 the modes of operation of the system are similar to those detailed for WATSUN-PV 1.0 for a stand-alone battery backup system. There are two key differences in the manner in which the simulation is performed.

i) Whereas in WATSUN-PV 1.0 the mode of operation for the system was fixed for the hour, in version 2.0 the mode may change within the hour depending primarily upon changing states of charge within the battery. In a given hour, if the battery becomes depleted upon discharge, the system may change from delivering the full (total) load to the essential load and finally to not delivering any energy to the load.

ii) The statistics compiled regarding loss of load conditions are determined by the worst case mode for the hour. Thus in a case as described above, in which the system delivers the full load at the beginning of the hour, but ends with a complete loss of load, the reported statistic is an hour with loss of load.

Further information regarding the details of the simulation may be obtained by contacting the WATSUN Simulation Laboratory.

7 Weather Data Options

7.1 TMY and 1970 Weather Files

The WATSUN Simulation Laboratory can provide weather files for a large number of North American cities. Some of these are available as Typical Meteorological Years (TMYs). A TMY is generated from 10 years of meteorological data. The "most representative" January is chosen from the 10, followed by the most representative February, and so on. The months are then concatenated together. The "most representative" months are chosen based on a large number of statistical factors, including the mean and the variability for radiation, temperature, and humidity, as well as the long term run structure for these values (e.g. if four or five cloudy days in a row is a frequent event in the month of February, then a February should be chosen which has some runs of cloudy days).

The format for TMYs is shown on the next page. The page following that shows the cities for which TMYs are available -- all those marked with an "*". The other cities shown are available as 1970 weather files only. The 1970 files contain only radiation and temperature, so they cannot be used to run photovoltaic simulations. These files can be modified by the WATSUN office to include false values for windspeed and humidity, so that they can be used with WATSUN-PV. Since the dependence on windspeed is weak, and there is no dependence of a photovoltaic system on humidity, the results will be reasonable.

MONITORED WEATHER DATA FORMAT

Header YEARXLXCITYNAMEPROVINCEXLATITXSLOPEXAZMTHXSTAX-
LENXPARXEXP
Format FORMAT (A4,1X,I1,1X,16A1,3F6.2,4(1X,I3))
Example 1988 1 KINGSTON ONT. 44.20 45.00 00.00 244 030 006 001

Where: YEAR = weather data year (1988 in this case)

L = leap year flag (1 for 1988, which is a leap year)

CITYNAMEPROVINCE = city name and province

LATIT = latitude (degrees)

SLOPE = slope on which measuring device was mounted (degrees

AZMTH = azimuth angle of measuring device (degrees)

STA = start day for weather file (244 for September)

LEN = number of days in weather file (30 for September)

PAR = number of parameters recorded per hour

EXP = exponential multiplier for load values: all load values will be multiplied by the factor 10**EXP before being used (e.g. in this case all load values will be multiplied by 10). This is to avoid losing significant figures.

X = blank, or in the case of LATIT or AZMTH this could be a negative sign.

Following the header, there may be up to six records for each day.

RECORD DATA

1. day number [ ], ground reflectance [ ], dry bulb temp. [°C]
   FORMAT (I3,1X,F3.1,17X,24I3)
2. global radiation on a horizontal surface [W/m²]
   FORMAT (24I4)
3. wind speed [km/hr]
   FORMAT (24I4)
4. relative humidity [%]
   FORMAT (24I4)
5. load for each hour - current or power [Amps or W]
   (Be sure to specify correctly in load block: 1 for current, 2 for power)
   FORMAT (24I4)
6. battery temperature for each hour [°C]
   FORMAT (24I4)

NOTES: 1. These records are repeated for each day of the year. If PAR in the header line is set to 4, the program will expect to see the first four records for each day. If it is set to five, the first five will be expected and if it is set to six, the first six will be expected. In other words, you cannot specify battery temperature without specifying the load.

2. The first hourly value is for the period midnight (0:00) to 1 AM (1:00). The last hourly value is for the period 11 PM (23:00) to midnight (0:00).

WEATHER DATA FOR THE WATSUN PROGRAM

CANADIAN DATA

1970 weather data is available for the following locations:
(Typical Meteorological Year (TMY) weather data is available for locations marked with an asterisk (*)).

ALBERTA
Calgary*
Edmonton*
Fort McMurray
Lethbridge
Medicine Hat*
Red Deer

BRITISH COLUMBIA
Kamloops
Penticton*
Prince Rupert
Vancouver*
Victoria*

MANITOBA
Brandon
Churchill
Thompson
Winnipeg*

NEW BRUNSWICK
Chatham
Fredericton*
Moncton
Saint John

NEWFOUNDLAND
Gander
St. John's*

NORTHWEST TERRITORIES
Fort Smith
Inuvik
Resolute

NOVA SCOTIA
Halifax
(TMY only)
Sable Island
Sydney*
Yarmouth

ONTARIO
Atikokan*
Big Trout Lake
Earlton
Geraldton
Gore Bay
Kapuskasing*
Kenora*
Kingston
London*
Mount Forest
Muskoka*
North Bay*
Ottawa*
Sault Ste Marie*
Simcoe
Sioux Lookout
Sudbury*
Thunder Bay*
Timmins*
Toronto*
Trenton*
Wiarton*
Windsor*

PRINCE EDWARD ISLAND
Summerside*
Charlottetown*

QUEBEC
Fort Chimo
Lake Eon
Montreal*
Poste de la Baleine
Quebec*
Riviere du Loup
Sherbrooke
Val d'Or

SASKATCHEWAN
Moose Jaw
Prince Albert
Regina*
Saskatoon
Uranium City

YUKON TERRITORIES
Whitehorse

U.S. DATA

Typical Meteorological Year (TMY) weather data is available for the following locations:

ARIZONA
Phoenix
Tucson

ARKANSAS
Fort Smith

CALIFORNIA
Fresno
Los Angeles
Sacramento
San Diego
San Francisco

COLORADO
Denver

DISTRICT OF COLUMBIA
Washington

FLORIDA
Jacksonville
Miami

HAWAII
Honolulu

ILLINOIS
Chicago

KANSAS
Dodge

LOUISIANA
Lake Charles

MAINE
Bangor

MASSACHUSETTS
Boston

MICHIGAN
Detroit

MISSOURI
St. Louis

NEBRASKA
North Omaha

NEVADA
Las Vegas

NEW MEXICO
Albuquerque
Roswell

NEW YORK
New York

NORTH DAKOTA
Bismark

OREGON
Redmond

SOUTH CAROLINA
Charleston

TEXAS
Brownsville
El Paso
Fort Worth
Laredo

UTAH
Bryce

VERMONT
Burlington

WASHINGTON
Seattle

WISCONSIN
Madison

NOTE: Synthetic weather data can be created for locations where hourly data is not available.

7.2 Stochastically Generated Weather Data

For other cities, WSL has the capability to generate a synthetic weather year using a program developed by V. Graham at the University of Waterloo. For a given site, the latitude, the mean monthly ambient temperatures, and the mean monthly clearness index (or daily radiation) are required. From this, a year of hourly values for radiation and temperature is generated, with windspeed and humidity set at arbitrary values for the whole year.

Note that this synthetic year is not a synthetic TMY. To obtain that, 10 synthetic years would have to be generated, and then a TMY could be made out of them.

WSL currently has monthly values for a large number of cities in the world, but the list is by no means complete. It is hoped that real weather data from Europe will be available soon, making it unnecessary to generate synthetic data for locations there.

7.3 Simulating Standard Day Tests

The WATSUN program can simulate a standard day test such as the one perfomed at the Ontario Research Foundation's National Solar Test Facility (NSTF). These tests are used to evaluate the relative performance of DHS systems and are run using weather data from "standard day" and a "typical" load schedule. The development of these standards is beyond the scope of this manual.

The test is performed until steady-state conditions are reached; that is, until the system produces virtually identical results for two consecutive days. The energy delivered by the system is recorded and used as a performance indicator relative to other systems.

The simulation of the standard day test uses the weather data from the "standard day" for each day of the simulation.

NOTE: This user is required to ensure all parameters are set to the appropriate values that accurately represent test conditions!

7.3.1 NSTF Standard Day - STAN

Although the NSTF standard day has not been established as a standard for PV systems, users may still want to use it with WATSUN-PV. To do so, the user would type the following command:

```
RUN  STAN  SIMU  12ARRAY  12BATT  HOUSE
```

where: SIMU, ARRAY, BATT, and HOUSE are data files.

7.3.2 Other Standard Day Tests

If you are interested in simulating any other standard day test, please contact the WATSUN Simulation Laboratory.

7.4 [illegible]

[illegible] at monitoring sites. Monitored data may be collected on a tilt, using a pyranometer mounted beside the collectors. It is also likely to be collected in shorter periods than one year. Some monitoring stations record hourly values for load (in watts or in Amps) and/or for battery temperature.

Users can now create their own weather files, in the format specified on pages 7.1-2 and 7.1-3, for any desired site. This can be done either by typing in the data in ASCII format, using the non-document feature on a word processor or a simple text-editor. It may also be created by writing a program to translate the data collected and recorded by monitoring equipment into the format shown. Such a program has been written by the WSL for use in translating the data recorded by TES equipment at various Canadian sites.

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